SOIL MANAGEMENT FOR ORGANIC CROP PRODUCTION

David Butler, Ph.D.
Assistant Professor
Organic, Sustainable & Alternative Crop Production
Plant Sciences Department, The University of Tennessee

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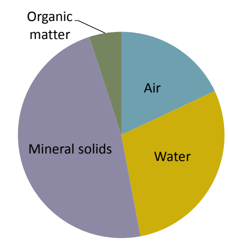
What is soil?

- Mineral solids
  - Sand, silt, clay
  - Mainly consist of O, Si, Al, Fe*, Mg*, Ca*, Na, K*
- Water/soil solution
- Air
- **Organic matter**
  - C (~ 58%), O, H
  - N*, S*, P*, other plant nutrients*



Soil management for organics

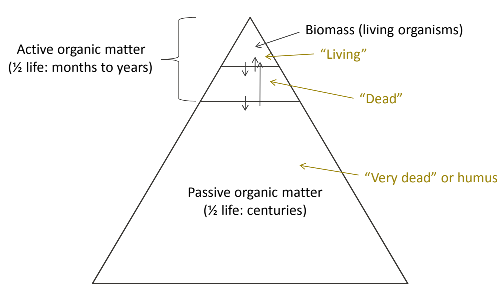
- National Organic Program (NOP) Rule
  - Does *not* define specific land practices
  - Identifies general soil management and environmental objectives
  - Producers and certifiers determine if practices meet these objectives
  - Also good general guidelines for "sustainable" soil management and improving soil quality, even if not organic

(Bellows, 2005)

National Organic Program (NOP) Rule

- 205.203 (a) "Select and implement tillage and cultivation practices that maintain or improve the physical, chemical, and biological condition of the soil and minimize erosion"
- (b) "Manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials"
- (c) & (d) "Manage plant and animal materials to maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances"

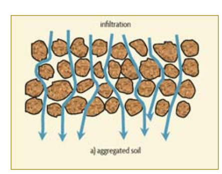
Soil organic matter



(Magdoff and van Es, 2009; figure adapted from Magdoff and Weil, 2005)

Active or labile organic matter

- Materials of recent origin
- High nutrient/energy value
- Non-aggregate protected
- Most important to:
  - Soil aggregation
  - Nutrient mineralization
    - Efficient cycling of N,P, & S
  - Micronutrient chelation
  - Plant growth-regulating substances
- <u>Most sensitive to management changes</u>



(Magdoff and van Es, 2009; figure adapted from Magdoff and Weil, 2005)

Passive or recalcitrant organic matter

- Physically protected or stable due to biochemical properties or mineral association
  - Humic substances, aliphatic molecules, lignins, etc.
- Responsible for much of CEC
  - Greater contribution to CEC in coarse-textured soils
- Nutrients in organic-mineral complexes
- Key role in water holding capacity, bulk density, etc.
- <u>Changes slowly with management</u>

(Magdoff and Weil, 2005)

Functions of soil organic matter

- Soil physical properties
  - Soil aggregation
    - Formation of granular structure of soil minerals and their resistance to slaking by water (slaking = breaking apart)
    - Greatest role of OM is binding macroaggregates (>0.25mm)
  - Soil water availability
    - Direct absorption of water
    - Enhancing and stabilizing aggregation

(Magdoff and Weil, 2005)

Functions of soil organic matter

- Soil chemical properties
  - Nutrient uptake and release
    - Nearly all N and large proportions of P and S occur as constituents of OM
    - Even in conventional systems, much of applied inorganic N cycles through the microbial biomass prior to plant uptake
  - Microbial enhancement of nutrient availability
    - N fixation, mycorrhizal fungi, micronutrient chelation

(Magdoff and Weil, 2005)

Functions of soil organic matter

- Soil chemical properties
  - Cation exchange capacity (CEC)
    - Controlled by *colloidal* fraction (i.e. clay and OM)
    - Relative contribution depends on amount of SOM, amount and mineralogy of clay, and pH
    - OM very important to CEC in coarse-textured and highly-weathered soils
  - Anion sorption
    - Allows P to be more available in acid soils, rather than bound to Fe and Al oxides
  - pH buffering
  - Plant growth regulating substances

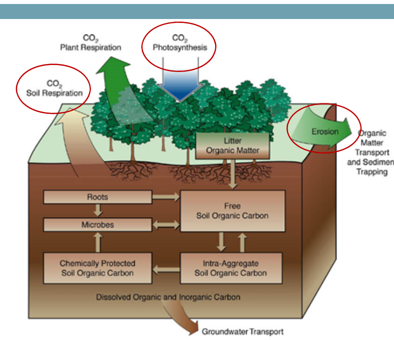
(Magdoff and Weil, 2005)

Functions of soil organic matter

- Soil biological properties
  - SOM is the raw material for soil biological activity
  - Microbial biomass
    - Provide labile C, N, P, S
    - Sink for C, N, P, S
    - Nutrient transformation
    - Mineral weathering
    - Influence aggregation
    - Some antagonistic to plant pathogens and parasitic nematodes
  - Macrofauna (earthworms, ants, termites), mesofauna (arthropods), and microfauna (nematodes, protozoa, rotifers)
    - Play role in cycling of C and nutrients, regulate microbial activity, enhance porosity, infiltration, etc.

(Magdoff and Weil, 2005)

Soil organic matter management



(www.climatescience.gov)

Environmental factors

- Climate
  - Temperature
    - Greater biomass produced, but decomposition is faster with higher temperatures
    - Less accumulation of SOM in warmer climates
  - Rainfall
    - Generally, SOM increases as precipitation increases
    - Very little biomass produced in arid regions
- Soil texture
  - Greater SOM in fine-textured soils (clay, silt)
    - Organic matter protected in aggregates, mineral associations
    - Smaller pores limit oxygen and thus decompostion

(Magdoff and van Es, 2009)

Environmental factors

- Drainage and landscape position
  - Greater SOM in wetter soils
  - Greater SOM in lower landscape positions
- Vegetation
  - Greatest SOM in soils that developed in grasslands
- Acidic soils
  - Slows SOM decomposition

(Magdoff and van Es, 2009)

Building soil organic matter

- Maximize plant productivity
  - Cover crops
  - Perennials
  - C4 plants (e.g. sorghum-sudangrass)
- Conserve crop residues
- Recycle local wastes
  - Composts
  - Manures

(Magdoff and Weil, 2005)

Building soil organic matter

- Balance decomposition of residues (nutrient mineralization) and accumulation of humus (i.e. "steady burn")
  - C:N ratio of residues
    - >25 to 30 (immobilization of N)
    - <25 to 30 (mineralization of N)
  - Incorporate high residue crops in rotation (e.g. grains)
    - 10 to 20% of biomass converted to stable humus
    - Mix small grains with legume cover crops
  - Root biomass plays an important role (perennials and biennials)
    - Slower decomposition, more stable organic matter
    - Continual root turnover
    - Well-distributed without using tillage

(Magdoff and van Es, 2009)

Preventing losses of SOM

- Erosion
  - Utilize conservation tillage practices
    - Maintain cover by residues at > 30%
    - Reduce tillage
  - Utilize cover crops
  - Incorporate perennials
- Soil respiration
  - Reduce tillage and soil disruption
  - Reduce use of synthetic fertilizers

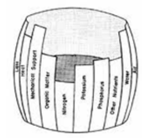
Plant nutrients

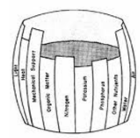
- *"A chemical element essential for plant growth and reproduction"*
- Derived from air or water
  - C, H, O
- Macronutrients (> 0.1% of tissue)
  - N, P, K, Ca, Mg, S
- Micronutrients (< 0.01% of tissue)
  - Fe, Mn, Cu, B, Zn, Mo, Cl, Ni
- Soil fertility is the capacity of the soil to provide nutrients for plant growth

(Barker and Pilbeam, 2007)

Nutrients and soil fertility

- Sprengel-Liebig law of the minimum
- Growth controlled by the limiting resource
- Not necessarily nutrients, could also be temperature, water, genetics, etc.





(Image from waternut.org)

Nutrients and soil fertility

- Reductionist vs. systems approach
  - Goal is not to replace synthetic conventional input with organic input
    - Must shift management to a whole systems approach
    - Not "input substitution"
  - How do the diversity of organisms within the soil and the diversity of plants in the cropping system interact and affect soil fertility?
  - How can the ecological system be managed to optimize fertility and sustainability?

Soil pH

- Measure of soil acidity or alkalinity (concentration of H^+ ions)
- Measured on a log scale (1 to 14)
- Most crops perform best at slightly acidic pH (6 to 6.5)
- Nutrient availability is greatest near neutral pH
- Acidic soils
  - Can be adjusted using lime ($CaCO_3$ or $CaMg(CO_3)_2$)
  - Increase soil organic matter
- For acid-loving crops
  - pH can be lowered by application of elemental sulfur (S)
- Materials generally must be from a mined source, without industrial processing that changes chemical structure

Nitrogen

- Earth's atmosphere is 78% N by volume
  - ~ 3 tons of N per ft^2 of Earth's surface
  - In the form N_2
  - Must be converted (fixed) to NH_3 or NH_4 before it can be utilized
- In plants: DNA, RNA, proteins
- Most organic systems are N-limited
- Nitrogen transformations
  - Fixation (atmospheric, industrial, biological)
  - Mineralization
  - Nitrification
  - Denitrification and volatilization

Mineralization

- Organic N → NH_4^+
- Soil organic matter, plant residues, manures, etc.
- Optimum conditions
  - 95 deg F
  - pH 7
  - 50% water filled pore space
- Positive charge allows it to be held tightly by negative soil charges
- Mineralized N can be *immobilized* (into organic N forms) by soil microbes

(Cabrera, 1998)

Mineralization

- What is the mineralization rate of SOM?
- General assumption:
  - ~ 20 lbs N $acre^{-1}$ for every 1% SOM mineralized annually
  - So, for a soil with 2% organic matter (0 to 6" sample), we would expect a release of 40 lbs N per $acre^{-1}$ yr^{-1}
- Temperature, precipitation, aeration, management…

(Grubinger, 1999)

Nitrification

- NH_4 converted to NO_3 by nitrifying soil bacteria
- Optimum nitrification at 86 deg F, pH 7, and ~50% WFPS (needs oxygen!)
- Acidifying effect in the soil
- Counterbalanced in organic situations by the pH increase due to mineralization
- NO_3 is negatively charged (like soil minerals) and leaches easily

(Cabrera, 1998)

Denitrification and volatilization

- Denitrification
  - NO_3 converted to gaseous forms of N
  - Occurs in soils when oxygen is depleted by either saturation or high biological activity
- Volatilization
  - NH_4 converted to gaseous NH_3
  - Occurs primarily when high concentrations of NH_4 are present under high pH (7.5+)
  - e.g. urea-based fertilizers or poultry litter applied to the soil surface

(Cabrera, 1998)

NOP allowed N sources

Material	% N	Availability
Manures	1 to 4	moderate
Composts and residues	< 1	slow
Cover crops!	0.5 to 3	slow to moderate
Blood meal	12	rapid
Feather meal	15	moderate
Seed meals	5 to 7	moderate to rapid
Alfalfa meal	4	moderate to rapid
Fish emulsion	2 to 5	rapid
Chilean nitrate*	13	rapid
Other animal, plant residues and byproducts	N/A	N/A

(Barker and Pilbeam, 2007)

Residual N mineralization

Years	N mineralized, lbs N $acre^{-1}$ Single application	N mineralized, lbs N $acre^{-1}$ Two applications	N mineralized, lbs N $acre^{-1}$ Annual application
1	100 (50%)	100	100
2	16 (8%)	116	116
3	10 (5%)	26	126
4	4 (2%)	14	130
5	2 (1%)	6	132

- Broiler litter application at 4 tons $acre^{-1}$ (assuming 2.5% total N)
- 200 lbs total N $acre^{-1}$

(Adapted from Barker, 2010)

Phosphorus

- *Phosphorus*, not phosphorous
- DNA, RNA, ATP
- Lipids, carbohydrates, proteins, enzymes, other plant metabolites
- Increases strength of cell walls
- Increases lateral root development
- Essential to flowering
- Commonly limits plant growth due to low solubility in soils

(Barker, 2010)

Phosphorus

- Many agricultural soils have ample P due to history of manure and fertilizer application
  - Builds up when manures applied to meet N needs
  - Availability of P may be limited due to soil minerals, pH
- Solutions:
  - P solubilizing cover crops (e.g. buckwheat, lupins)
  - Increase organic matter
  - Encourage mychorrizal fungi (reduce tillage and fungicide use)

NOP allowed P sources

	P2O5 (%)	P (%)	Availability
Broiler litter	2.5	1.1	Moderate
Composts and manures	1	0.4	Moderate
Rock phosphate	30	13	Very low
Phosphatic clays	20	9	Very low
Bonemeal	13	6	Moderate
Alfalfa meal	3	1.3	Moderate

(Adapted from Barker, 2010)

Potassium

- Second to N in plant accumulation
- Mobile element in plants
- Important to synthesis of chlorophyll, complex carbohydrates, and proteins
- Promotes water movement into cells (turgor pressure)
- Required for development of fruits and seeds, roots and tubers

(Barker, 2010)

Potassium

- High levels of K in soils (up to 50,000 lb $acre^{-1}$ in clay loam)
- However, most of this is fixed in primary minerals (90 to 98%; feldspar, mica)
- Nonexchangeable (1 to 10%)
- Exchangeable (1%)
- Soil solution (<<<1%)

(Barker, 2010)

NOP allowed K sources

	K_2O (%)	K (%)	Availability (%)
Manures	2 to 3	1.7 to 2.5	100
Composts	1	0.8	100
Vegetative plant residues	4	3.3	100
Seed residues	1.5	1.2	100
Wood ashes	10	8.3	100
Greensand	7	5.8	limited
Potassium sulfate*	48	40	100
Potassium magnesium sulfate* (langbeinite)	22	18	100

(Adapted from Barker, 2010)

Sulfur

- Essential to protein synthesis
- Part of compounds that provide distinctive flavors to brassicas (cabbage, mustard, broccoli, etc.) and alliums (onions, garlic, shallots)
- Likely plays a role in conferring resistance to fungal pathogens and insect pests
- Moderately mobile in plants, deficiency symptoms on young leaves
- Sandy, low organic matter soils most likely to be sulfur deficient (SO_4^{2-})

(Barker, 2010, Bloem et al., 2005, Francis et al., 2009)

Sulfur

- Most of sulfur in soil is in soil organic matter
- ~ 15 lbs ac^{-1} yr^{-1} in precipitation
- ~ 800 lbs ac^{-1} in soils
- Plant requirement ~ 15 to 30 lbs ac^{-1}, though some higher
- Deep-rooted crops effective at uptake of SO_4^{2-} adsorbed in subsoils
- Sulfur amendments
  - Manures, plant residues (~ 0.5%)
  - Elemental sulfur (lowers pH)
  - Gypsum (mined; $CaSO_4$)
  - Epsom salts ($MgSO_4$)
  - Potassium sulfate or potassium magnesium sulfate (mined)

(Barker, 2010; Francis et al., 2009)

Calcium

- Much of calcium in pectin between cell walls
- Also has roles in cell division, regulation of membrane permeability, and legume nodulation
- Immobile in plants so deficiency symptoms begin at growing points
- Blossom end rot a common deficiency syndrome in tomato and pepper, also occurs less frequently in eggplant and watermelon

(Barker, 2010)

Calcium

- Deficiency most common in acid, sandy, highly-leached soils or in **dry soils**
- Ca^{++} saturation typically accounts for 60 to 70% of CEC in fertile agricultural soils
- Total calcium in humid region soils ~ 1,000 to 8,000 lbs ac^{-1} without liming
- Crop uptake 30 to 50 lb ac^{-1} yr^{-1}
- Calcium amendments:
  - Calcitic and dolomitic lime
  - Gypsum (mined; $CaSO_4$)
  - Rock phosphate
  - Bonemeal
  - Plant residues (1 to 4%), manures (~ 1%)

(Barker, 2010; Francis et al., 2009)

Magnesium

- Required for chlorophyll synthesis
- Metabolism of ATP, enzyme activation
- Deficiency common is acid, leached, sandy soils
- Mobile element in plants
- Yellowing of older leaves, initially between veins
- Very important in forage crops, as low Mg may lead to grass tetany in livestock

(Barker, 2010)

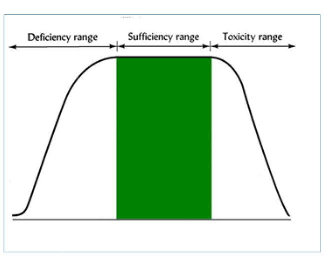
Magnesium

- ~ 6,000 lbs ac^{-1} in primary minerals
- Held as exchangeable cation (Mg^{++})
- Plant uptake 15 to 30 lbs ac^{-1} yr^{-1}
- Magnesium amendments
  - Dolomitic lime, Epsom salts ($MgSO_4$), Potassium magnesium sulfate (mined)
  - Manures, plant residues

(Barker, 2010)

Micronutrients

- Macronutrients = wide range
- Micronutrients = narrow range
  - More likely to cause toxicity, yield loss with over-application



(Adapted from: J. Gruver, WIU)

Micronutrients

- Most are metals (exception of Boron)
- Most are limited in availability with increasing soil pH (exception of Mo)
- Application of manures and composts in organic systems make micronutrient deficiencies uncommon
- Building soil organic matter has positive impact on micronutrient availability

(Barker, 2010; Francis et al., 2009)

Boron

- Most likely micronutrient to be limiting in organic systems
- Important to pollination and seed/fruit development
- Non-mobile in plants
- Stem die-back, splitting, cracking, corking, hollowing, dry rotting can all result from B deficiency

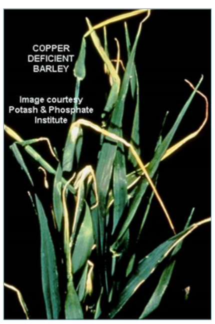
(Barker, 2010; Francis et al., 2009)

Boron

- Leaching in humid regions often causes deficiency
- ~ 10 to 220 lbs ac^{-1} in soils
- Crops remove 1 to 2 lbs B ac^{-1} yr^{-1}
- Very narrow sufficiency range
- High demand crops include alfalfa, tomato, cauliflower, cabbage, cotton
- Boron amendments
  - Borax (sodium tetraborate)
  - Manures, residues
  - Also synthetic sources with documented need** (e.g. Solubor, Granubor)

(Barker, 2010; Francis et al., 2009)

Copper (Cu) deficiency



- ~ 10 to 300 lb ac^{-1} in soils
- Tightly sorbed to organic matter
- Deficiencies most common in peats, Histosols or acid, leached, sandy soils
- Toxicity is likely a greater concern in organic systems if using Cu-based fungicides (plant stunting, bluish-tint, leaf cupping)

(Photos from: umd.edu; Barker, 2010)

Manganese

- ~40 to 12,000 lbs ac^{-1} in soils
- Plant uptake is a few pounds $acre^{-1}$
- Most is precipitated as MnO_2
- Can become toxic below pH 5
- Deficiencies most likely in Histosols or acid, leached, sandy soils
- In TN, only common deficiency is in soybean when pH above 7.0 and low soil test levels
- Interveinal chlorosis on younger leaves

(Barker, 2010; Francis et al., 2009)

Molybdenum

- ~ 4 to 20 lbs ac^{-1} in soils
- Crop uptake < 1 ounce ac^{-1} yr^{-1}
- Can become deficient below pH 5.3
- Legumes, citrus, and brassicas most susceptible to deficiency
- Whiptail of cauliflower

(Barker, 2010; Francis et al., 2009)

Zinc

- ~ 150 lbs ac^{-1} in soils
- Decreased availability at higher pH
- Plant uptake a few lbs ac^{-1} yr^{-1}
- Relatively immobile in plants
- Only recommended use of Zn fertilizers in TN is for corn and snap bean

(Barker, 2010; Francis et al., 2009)

Soil testing

- UT Soil, Plant, and Pest Center
- Soil pH
  - Water
  - Buffer
- No routine soil analysis for N
  - Why?
  - How are recommendations developed?
  - What should we do for organic systems?
    - Soil organic matter

(Savoy, 2005)

Soil testing

- Mehlich 1 extractant
  - Weak, double acid extractant
  - Primarily used in the Southeast on acid soils low in CEC
  - P, K, Ca, Mg, Zn, Mn, Fe, Cu, Na, B*
  - Values reported as lbs ac^{-1}
    - Very, very, very, very, very misleading
    - Values are of little to no value without field calibration
    - Use as an index, not a raw value

(Savoy, 2005)

Soil testing

- P and K results reported as:
  - Low (L): Crop likely to respond to application of nutrient. If not applied, deficiency may occur and crop will typically yield 75% or less of potential
  - Medium (M): Crop may or may not respond to nutrient application. Symptoms of deficiency unlikely and production can be expected at 75% or greater of potential.
  - High (H): The soil will produce at or near 100% potential without nutrient application
  - Very High (VH): Nutrient supply in soil is well in excess of the amount needed, no further application recommended.

(Savoy, 2005)

Soil testing

- Secondary nutrients and some micronutrients reported as:
  - Sufficient (S)
  - Deficient (D)
- Calcium soil test used solely for tomato and pepper recommendations
  - If soil test Ca <500 and pH above 6.1, 500 lbs ac^{-1} gypsum recommended
  - Otherwise reported as 'S'

(Savoy, 2005)

Soil testing

- Magnesium deficiencies most likely in Plateau or Highland Rim soils
  1. If soil test Mg <40, 20 lbs ac^{-1} recommended for grapes, tomatoes, tobacco, and cabbage
- Sulfur soil tests are of limited predictive value
  - Response to S amendment most likely in low organic matter soils (<1% SOM)
- Boron values are reported, but without ratings
  - Common practice is to recommend 2 lbs ac^{-1} for alfalfa, broccoli, cauliflower, and cabbage and ½ lb ac^{-1} for cotton when pH above 6.0
  - Borax can typically be applied without "documented need" in organic systems

(Savoy, 2005)

Soil testing

- Copper test used only to monitor potential toxicities
- No established need in TN for iron fertilization for agronomic, vegetable, or fruit crops
- Manganese recommended for soybeans
  - pH > 7.0 and soil test Mn below 20
  - 20 lbs ac^{-1} application
- Molybdenum
  - Seed treatment for soybeans
- Zinc
  - Used for corn and snap beans if soil test Zn less than 2
  - Also a routine recommendation for pecans

(Savoy, 2005)

Choosing a cover crop

- **Step 1:** Identify what function is needed from the cover crop
  - What is limiting production in a given system? (e.g. low fertility? poor soil structure? weed or pathogen populations?)
  - What functions can cover crops serve?

(Miles and Brown, 2003)

Functions of cover crops

- Provide nitrogen
  - Legumes- symbiotic relationship between legumes and rhizobia bacteria that fix atmospheric nitrogen Increase soil organic matter and soil biological activity
  - Major influence on most soil properties (bulk density, porosity, nutrient and water holding capacity, etc.)
  - High biomass producing cover crops, generally grass species
  - Solubilize less soluble nutrients such as phosphorus

(Miles and Brown, 2003)

Functions of cover crops

- Scavenge nutrients remaining after a cash crop
  - Potentially available to following cash crop
  - Prevents leaching losses, which improves soil fertility and decreases environmental impact
  - Generally non-legumes, primarily grasses
- Prevent soil erosion
  - Covers soil during fallow periods, preventing loss of soil and associated nutrients
  - Rapidly growing species are best, but most cover crops fill this role

(Miles and Brown, 2003)

Functions of cover crops

- Improve soil structure
  - Increasing soil organic matter is key
  - Non-legumes, which break down slowly best serve this function (grasses)
- Improve drainage
  - Deep-rooted cover crop species can break through compacted soil layers and improve drainage
  - Organic matter improves soil aggregation
  - Bell beans, clovers, cereal grains, etc.

(Miles and Brown, 2003)

Functions of cover crops

- Protect water quality
  - Prevent erosion
  - Scavenge nutrients
- Provide mulch to suppress weeds and conserve soil moisture
  - High biomass and high C:N ratio species
  - Primarily grasses

(Miles and Brown, 2003)

Functions of cover crops

- Provide habitat for beneficial insects
  - Most applicable in permanent systems (e.g. orchard groundcovers) but also applicable in annual systems

(Clark, 2007; photos: marabelgroup.com, panoramio.com)

Functions of cover crops

- Suppress weeds
  - Through competition, allelopathy, shading, etc.
  - Cereal rye, sorghum-sudan, other grasses
  - Rotation of cover crops as well, so that weeds that compete well with that cover crop do not build up
  - Can be used as a mechanically-killed mulch in no-till organic systems to suppress weeds
- Suppress soilborne pests and diseases
  - Some species known for their ability to suppress certain pathogens (e.g. sorghum-sudan or sunn hemp and root-knot nematodes)
  - Others are good hosts for root-knot nematodes (certain clovers)
  - Brassicas used for biofumigation, nematode-trapping effects

(Miles and Brown, 2003)

Choosing a cover crop

- Step 2: Identify the cover crop planting niche
  - Where does the cover crop fit in the crop rotation?
    - Warm-season or cool-season
    - Other climatic variables
      - Precipitation
      - Temperature (summer highs, winter lows)
      - Day-length
    - Compatibility with previous and subsequent cash crops
  - Define timing of critical cash crop operations, so that cover crop management does not conflict

(Miles and Brown, 2003)

Choosing a cover crop

- Step 3: Select cover crop that meets goals and requirements of steps 1 & 2
  - Consider benefits and drawbacks (perfect fit is unlikely)
  - Consider cost and availability of seed (even more so with organic and untreated seed)
  - Consider management costs (field operations needed to plant, kill, etc.)

(Miles and Brown, 2003)

Cover crop costs

- Direct costs
  - Seed
  - Establishment (e.g. tillage, drilling, irrigation)
  - Termination (e.g. tillage, rolling)
- Indirect costs
  - Interference with following cash crop
    - Soil temperature
    - N release
  - Management issues
    - Difficult termination
    - Weediness

(Snapp et al., 2005)

Cover crop costs

- Opportunity costs
  - Cost of forfeit income if a cash crop alternative was feasible
  - Can be the most important limitation

(photo: trekearth.com; Snapp et al., 2005)

Cover crop classes

- Cool-season annuals
  - Legumes
  - Non –legumes
    - Grasses
    - Broadleaves
- Warm-season annuals
  - Legumes
  - Non-legumes
    - Grasses
    - Broadleaves
- Perennials and biennials/ley/sod crops

(photo: winemakermag.com)

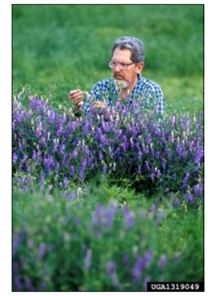
Cool-season annual legumes

- Crimson clover *(Trifolium incarnatum)*
  - N contribution 70 to 150 lbs/acre
  - Planted in mid-fall in TN, rapid spring growth
  - Grows well mixed with small grains (e.g. rye, triticale, wheat)
  - Good pollen source for bees
  - Not winter-hardy in colder climates (zone ~ 6 +)

(Clark, 2007; photos: oregonclover.org)

Cool-season annual legumes

- Hairy vetch *(Vicia villosa)*
  - N contribution 100 to 150 lbs/acre
  - Planted in mid-fall in TN
  - Grows well mixed with small grains (e.g. rye, triticale, wheat)
  - Quickly smothers spring weeds
  - Hard-seeded, can become a weed problem
  - Very winter hardy (zone ~ 4 +)



(Clark, 2007; photo: USDA-ARS)

Cool-season annual legumes

- Winter Pea *(Pisum sativum* ssp. *arvense)*
  - N contribution 90 to 150 lbs/acre, as much as 300 lb/acre reported
  - Planted in mid-fall in TN
  - Low water use
  - Not as winter hardy as hairy vetch or crimson clover (zone ~ 7 +)

(Clark, 2007; photos: agronomy.ifas.ufl.edu, seedsofchange.com)

Cool-season annual legumes

- Lupin (*Lupinus albus*, *L. angustifolus*, etc.)
  - N contribution 100 to 150 lbs/acre
  - Aggressive taproots
  - Easy to kill mechanically
  - Not as winter hardy as hairy vetch or crimson clover (zone ~ 7 +; no farther north than the TN valley)

(Clark, 2007; photos: edamameseed.com; ucdavis.edu)

Cool-season annual legumes

- Fava or bell bean *(Vicia faba)*
  - Grows well in cool conditions
  - High biomass producer
  - Deep taproot
  - Over 100 lbs N/acre
  - Not as winter hardy as other cool-season legumes (zone ~ 7 to 8 +)

(Clark, 2007; photos: ofrf.org, wikimedia.org)

Other cool-season annual legumes

- Berseem clover *(Trifolium alexandrinum)*
- Balansa clover (*Trifolium michelianum)*
- Medics *(Medicago spp.)*
- Common vetch *(Vicia sativa)*
- Red clover* *(Trifolium pratense)*
- Sweet clover* *(Melilotus officinalis and M. alba)*

*biennials

(Clark, 2007; photos: USDA-ARS; tamu.edu, nps.gov, permaculture.org.au, dnr.wi.gov, www.uwyo.edu)

Cool-season non-legumes

- Rye (*Secale cereale*)
  - **Should not be confused with ryegrass (*Lolium multiflorum*)**
  - Very cold hardy
  - Good nutrient scavenger
  - High early season biomass
  - Allelopathic (DIBOA)
- Other cereal grains
  - Wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), triticale (× *Triticosecale)*
  - Oats (*Avena sativa*) can be used when winter-kill is desired

(Clark, 2007; photos: ces.ncsu.edu, tamu.edu)

Cool-season non-legumes

- Brassicas
  - Mustards *(Brassica juncea, Sinapsis alba, B. carinata, B. nigra)*
  - Rapeseed & canola *(B. napus, B. rapa, B. campestris)*
  - Radish *(Raphanus sativus)*
  - Arugula *(Eruca sativa)*
  - Pest suppression
  - Good nutrient scavenging ability
  - Winter hardiness varies
  - Attract beneficial insects

(Clark, 2007; photos: plantsolutionsltd.com, USDA-SARE)

Cool-season non-legumes

- Annual ryegrass *(Lolium multiflorum)*
  - Good nutrient scavenging
  - Good biomass production with sufficient N and moisture
  - Residue does not persist as well as cereal grains
  - Not as cold hardy as cereal rye
  - Can become a weed

(Clark, 2007; photos: osu.edu)

Cool-season non-legumes

- Phacelia (*Phacelia tanacetifolia*)
  - Native to CA, but developed as cover crop in Europe
  - Good catch crop, smother crop, and pollen source
  - Can be grown as summer or winter annual, though not hardy below ~ 20 F

(Clark, 2007; photos: kentagextension.blogspot.com; larnerseeds.com)

Warm-season legumes

- Sunn hemp *(Crotalaria juncea)*
  - Rapid biomass and N production (120 lbs N/acre in 9 weeks)
  - Does best in very warm conditions
  - Limited by seed cost and availability in U.S.
  - Suppressive to root-knot and reniform nematodes

(Clark, 2007; photos: J. Cotton Sci.)

Warm-season legumes

- Bean-like
  - Cowpea *(Vigna unguiculata)*
  - Velvet bean *(Mucuna pruriens)*
  - Soybean *(Glycine max)*
  - Hyacinth bean (*Lablab purpureus*)
  - Jack bean (*Canavalia ensiformis*)
- High biomass and N production
- Work well mixed with warm-season grasses

(photos: J. Cotton Sci.; velvetbean-mucuna.com; cilr.uq.edu.au)

Warm-season legumes

- Hairy indigo (*Indigofera hirsuta*)
- Alyce clover (*Alysicarpus vaginalis*)
- Fenugreek (*Trigonella foenum-graecum*)

(photos: ufl.edu; marinelifephotography.com; truesaffron.com)

Warm-season non-legumes

- Sorghum-sudangrass hybrid *(Sorghum bicolor x S. bicolor* var. *sudanense)*
- Very high biomass production, good for building soil organic matter
- High allelopathy and very competitive with weeds
- Suppressive against pathogens and nematodes
- Sudangrass also works well

(Clark, 2007; photos: agroatlas.ru)

Warm-season non-legumes

- Millets
  - Pearl millet *(Pennisetum glaucum)*, Japanese millet *(Enchinochloa frumentacea)*, & German (foxtail) millet *(Setaria italica)*
  - High biomass
  - Very tolerant of drought, heat, low fertility

(photos: preferredseed.com, uga.edu, hffinc.com)

Warm-season non-legumes

- Buckwheat *(Fagopyrum esculentum)*
  - Rapid growth (maturity in 45 days)
  - Good smother crop
  - Attracts pollinators
  - Can seed easily and become weedy if not well-managed

(photos: cornell.edu)

Warm-season non-legumes

- Sesame (*Sesamum indicum*)
  - Likely to be suppressive against root-knot nematodes
  - Prefers very warm conditions
  - Extensive root system
  - Also has potential as an alternative crop

(photo: ksu.edu)

Perennial/ley/sod crops

- Longer fallow periods
- Build soil organic matter
  - Root biomass
- Legumes contribute high N
- Used for grazing, haying, etc
- Options
  - Alfalfa, red clover, white clover
  - Orchardgrass, tall fescue, etc.

(photos: uga.edu; uvm.edu; nrcs.usda.gov)

Always check with your certifier!

***Check with your organic certifier before changing your soil fertility management practices to ensure you are staying within NOP guidelines.