Soil Health

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Soil Health and Vegetable Production Extension Program 2009-2011

• Cover crop use in vegetable production
• No-till production
• Biofumigant crops
• Crop rotations
• Compost in vegetable production
• Soil health as a part of IPM programs for vegetables
Land Limited Rotations
Traffic Intensive Activities
Soil Disturbance, Tillage, Cultivation
Soil Health Indicators
Soil Health Visual indicators

- Soil color
- Erosion evidence
- Ponding, poor drainage
- Runoff
- Plant response
- Plant species (natives, weeds)
Soil Health - Soil Test Indicators, Chemical Indicators

- pH
  - Acidity, Al
- Organic matter
- Nutrients (P, K, Ca, Mg etc)
- Cation Exchange Capacity (CEC)
- Chemical contaminants
Organic Matter – Soil Health Driver

- **Food source**
  - Biological effects

- ** Decomposition products**
  - Biological effects
  - Chemical effects
  - Physical effects

- **Crops for organic matter**
  - Residue (previous crop)
  - Cover crops
  - Green manures
  - Biofumigants

- **Organic amendments**
  - Manures/bedding
  - Composts
  - Waste products
Stable Soil Organic Matter - Humus

- End decomposition products
- Relatively stable
  - Limited further decomposition
- High nutrient holding capacity
- High water holding capacity
Physical Soil Health Indicators

- Topsoil depth
- **Tilth**
- Structure
- Water holding
- **Water movement**
  - Infiltration
  - Percolation, **drainage**
  - Waterlogging
- **Compaction, Bulk density**
  - Surface compaction
  - Deep compaction
- Erosion
- Crusting, cracking
• Root growth, rooting depth, root activity
• Earthworms
• Microbial Diversity
  – Nematodes
  – Protozoa
  – Fungi
  – Bacteria, Actinomycetes
• Microbial activity
  – Aerobic
  – Soil improving
• Pathogen level
• Insects
• Weed species
• Native plant species
Soil Health as a Part of an Integrated Pest Management Program for Vegetable Crops – A Prescriptive Approach

Gordon C. Johnson, Joanne Whalen, Bob Mulrooney, Kate Everts – Participating Extension Specialists
Mason J. Newark – Program Assistant
University of Delaware
Overview

• Soil quality and health research has been conducted for > 20 years now.
  – University of Nebraska - John Doran
  – Cornell University ~10 years, University of Vermont and UMD-collaborators with Cornell
  – Specific research soil health issues in vegetables and fruits – many researchers throughout the region

• Various disciplines within soil health are well established and well known
  – Soil microbiology
  – Plant pathology
  – Soil ecology
  – Soil science
Soil Health Evaluation
What problems need to be addressed?
What do you need to know?

Pest identification
Pest levels
Pest locations
Field pest history
Rotation information
Variety information

Compaction evaluation
Tillage practices
Traffic patterns
Rooting evaluation
Root pest evaluation
Rotation - cropping
Current publications

- Training manual by Cornell
  - Used as a guide for sampling and assessment
  - Broad overview on diagnostics
  - Good foundation on what is a healthy soil
Characteristics of a healthy soil

- Good Tilth
- Sufficient (not excessive) nutrients
- Low pathogen population
- Large population of beneficial organisms
- Low weed pressure
- Free of chemicals/toxins that may harm desired crop
- Resistance to degradation
- Resilience in adverse conditions
How are these characteristics measured?

• Traditional soil testing
  – Nutrient levels, organic matter, pH
• Specialized testing
  – Aggregate stability, soil respiration/microbial biomass, root health
• Scouting, site specific diagnostics
  – Identifies weed, pest, and pathogen pressures i.e. nematode testing, field records, specific pathogen ID
What makes our program unique?

- Integrated extension approach with field specific recommendations
  - Multi-year
  - Cooperators with identified problem fields
  - Soil health measurements, specific diagnostics for problems
  - Prescriptive management plan developed
  - Follow through, evaluation
  - Improving sites while simultaneously surveying for future
4 phase approach

Phase I
Identifying Growers and Problem Fields

Phase II
Sampling, Soil Health Assessment & Diagnostics

Phase III
Prescription Developed and Implemented

Phase IV
Assessment of Prescription Effectiveness

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Phase I: identification of cooperating growers and fields

• Identified by personal contact with agents or specialists; presentations at growers meetings, newsletters, articles, etc.

• Characteristics of growers include:
  – Heavy vegetable and/or fruit rotations
  – Historic problem fields
  – Smaller growers with limited rotations tend to have best “fit”
Evaluations and Diagnostics
Field Level

- Soil Health Evaluations
  - Chemical, Physical, Biological
- Pest History
  - Diseases, Nematodes
  - Insects
  - Weeds
- Pest Survey, Scouting, Evaluations
  - Insects
  - Weeds
  - Nematodes
  - Diseases???
    - Bioassay
    - Crop samples
    - Soil samples???
      - Traditional microbiology
- Compaction (penetrometer)
- Drainage – infiltration, topography, soils maps

Future
- DNA techniques
  - Presence of specific pathogens
  - Quantification of specific pathogens
  - Microbial diversity
  - Quantification of specific beneficial soil organisms
Sampling

- Sampling consisted of standard soil probe within 0-8” layer
- Compaction ratings taken down to 16” (subsoil layer)
- Additional samples taken with a standard trowel for tests requiring high volumes of soil.
- Second sampling taken in late July/Early August for nematode assays and respiration rates
- Specific samples in crop season for diseases, other pests.
Phase II: Soil Health Measurements

• Traditional soil testing
  – M3 nutrient analysis (P, K, Ca, Mg, Mn, Zn, Cu, Fe, B, S, Al)
  – OM% by LOI
  – pH, buffer pH, Estimated CEC, base saturation

• Specialized testing
  – Aggregate stability
  – Soil Respiration
  – Root bioassay
Aggregate stability

• Indicative of organic matter content

• Low aggregate stability responsible for surface crusting after rainfall

• Can result in decreased germination and poor stands
Corn seedling emerging from crusted soil

http://www.extension.iastate.edu
Solvita soil test

- Used for measurement of
  - Soil respiration
  - Microbial biomass
  - Gross nitrogen release

- 24hr test which uses a colormetric paddle system
Paddles within samples to be analyzed using the Digital Color Reader (DCR)
Root bioassay

- Simple approach to identifying soil pathogens
- Use a susceptible organism grown in the soil
- Unfortunately, poor germination can skew results
Healthy, well developed root system

Stunted, sickly looking root system

Health Rating: 8/10

Health Rating 3/10
Specific (Field) Diagnostics

- Nematodes
  - Sampled by field staff
  - Extracted and counted by Bob Mulrooney
- Pathogens, insects, and weed pressure
  - Present and historical densities and diagnostics
  - Pathogens focused on soil borne disease organisms
- Soil Compaction
  - Surface
  - Subsoil
Typical Delaware results

- High subsurface compaction
- Low organic matter
- Rotational issues
- Nematodes, fungal pathogens
Phase III: Prescriptive treatments developed, Grower implements plan

- Based on identified problems, soil health data collected, diagnostics and grower concerns
- Rotation changes
- Most often recommended other biological treatments
  - Biofumigants for soil diseases
  - Biodrilling crops for compaction
  - Cover crops for weed/disease suppression
  - Green manures and soil amendments for organic matter building
Soil Health “Toolbox”
Prescription - Processing Peas (3 year rotation)

Limitations: physical, pathological

- Compaction
- Low OM
- Root rots

- Early maturing field corn?
  - Or sweet corn
- Harvest September
  - Or earlier for sweet corn
- Plant radish September
- Radish winter kills by January
- Limited tillage (turbo till) or no-till peas
- Pickle cucumbers, sweet corn, or other non-legumes (no snap beans, lima beans, or soybeans)
- Rye or wheat cover crop
- Corn
Prescription – Lima Bean Diseases (3 year rotation)

LIMITATIONS - pathological
- Rhizoctonia and Fusarium
- White mold
- P. capsici
- Pythium

• Small grain
• Harvest June
• Plant sweet corn or other non-legume for early September harvest
  – Alternative sorghum cover crop
• Apply Contans biological fungicide
• Plant rapeseed early September
• Incorporate rapeseed April
• Apply second application of Contans biological fungicide
• Apply compost 3 t. per acre
• Plant annual ryegrass
• Kill annual ryegrass Late May
• No-till lima beans June

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Phase IV: Assessment of Prescription Effectiveness

- Second round of soil health measurements and diagnostics post treatment
- Vegetable crop performance
- Overall assessment of improvements in soil health and effectiveness at addressing problems
Soil Health “Toolbox”
Composts
Creating Pest Suppressive Soils

- Antagonistic organisms
  - Competitive displacement
- Biological control organisms
  - Predation, parasitism
- Antibiosis, fungistasis
  - Root zone community
  - Soil
- Induced plant resistance
  - Plant defenses
- Modified habitat
  - Unfavorable environment
    - Water relations, aeration
    - Chemical
# Rotations

## Table 1: Rotation Periods to Control Vegetable Diseases

<table>
<thead>
<tr>
<th>VEGETABLE</th>
<th>DISEASE</th>
<th>PERIOD WITHOUT A SUSCEPTIBLE CROP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>Fusarium root &amp; crown rot</td>
<td>8 years</td>
</tr>
<tr>
<td>Beans</td>
<td>Root rots</td>
<td>3 to 4 years</td>
</tr>
<tr>
<td></td>
<td>Anthracnose</td>
<td>2 years</td>
</tr>
<tr>
<td></td>
<td>Bacterial blight</td>
<td>2 years</td>
</tr>
<tr>
<td>Beets</td>
<td>Cercospora leaf spot</td>
<td>3 years</td>
</tr>
<tr>
<td>Cabbage and related plants</td>
<td>Fusarium yellows</td>
<td>Not effective.</td>
</tr>
<tr>
<td></td>
<td>Blackleg (Phoma)</td>
<td>3 to 4 years – Also avoid turnip.</td>
</tr>
<tr>
<td></td>
<td>Black Rot</td>
<td>2 to 3 years – Also avoid turnip.</td>
</tr>
<tr>
<td></td>
<td>Rhizoctonia</td>
<td>3 years</td>
</tr>
<tr>
<td></td>
<td>wirestem and head rot</td>
<td></td>
</tr>
<tr>
<td>Carrots</td>
<td>Leaf blights</td>
<td>2 years</td>
</tr>
<tr>
<td>Corn</td>
<td>Smut</td>
<td>6 years – Not a reliable control.</td>
</tr>
<tr>
<td></td>
<td>Leaf blights</td>
<td>1 year</td>
</tr>
<tr>
<td>Cucumber</td>
<td>Scab &amp; leaf spots</td>
<td>2 years</td>
</tr>
<tr>
<td>Eggplant</td>
<td>Verticillium wilt</td>
<td>4 years – Also avoid tomato, potato, pepper, strawberry, and brambles.</td>
</tr>
<tr>
<td>Lettuce</td>
<td>Bottom rot &amp; drop</td>
<td>3 years</td>
</tr>
</tbody>
</table>
Positive Effects of Specific Cover Crops

**Graminiaceous species**

- Provide relatively high carbon inputs
- Intensive rooting
- Improve soil structure
- Some provide disease suppression

**Leguminous species**

- Provide soil nitrogen
- Specific species provide disease suppression
Benefits of cover crops on beneficial organisms and plant disease

Cover crop amendments result in changes in the structure and activity of the soil microbial community

i.e. There are changes in what organisms grow best (are favored) on a green manure substrate and what these bacteria do to the pathogen and to disease development.
# Biofumigation With Brassica Species

## Table 1. Mustard classifications and common varieties.

<table>
<thead>
<tr>
<th>Species names</th>
<th>Common</th>
<th>Varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Brassica napus</em></td>
<td>Canola Rapeseed</td>
<td>Dwarf Essex</td>
</tr>
<tr>
<td><em>Brassica nigra</em></td>
<td>Black mustard</td>
<td></td>
</tr>
<tr>
<td><em>Brassica alba, Brassica hirta</em></td>
<td>White &amp; yellow mustards</td>
<td>IdaGold, Martegena, Tinley</td>
</tr>
</tbody>
</table>

### Glucosinolates Degradation Products

- **Isothiocyanate is the most important breakdown product of glucosinolates**
- **Used in Commercial fumigants**

**Isothiocyanate used in Vapam**

[Diagram showing glucosinolates degradation products with chemical structures of isothiocyanate and other related compounds]
Brassicaceae
Biofumigation with Brassica Species

Brassica Cover Crops Management

Simultaneous flail mowing and incorporation

Mathieu Ngouajio, Michigan State University
Department of Horticulture
Sun Hemp biomass production achieved an average of 5,200 pounds in 9 to 12 weeks over a two-year study at two locations in Alabama
Biotillage, Biodrilling, Root Zone Effects
Forage Radish and Oilseed Radish
Biomass - Mulch
### TABLE 2. EFFECT OF EARLY-KILLED RYE RESIDUES ON BARNYARDGRASS, REDROOT PIGWEED, AND TOTAL BIOMASS PER 1.0 M² IN NO-TILL PEAS ON A MARLETTE FINE SANDY LOAM

<table>
<thead>
<tr>
<th>Cover</th>
<th>Barnyardgrass (g)</th>
<th>Pigweed (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial mulch</td>
<td>50.2 b</td>
<td>1.4 b</td>
</tr>
<tr>
<td>MSU-13 rye</td>
<td>22 a</td>
<td>0.9 a</td>
</tr>
<tr>
<td>Wheeler rye</td>
<td>12.7 a</td>
<td>0.5 a</td>
</tr>
</tbody>
</table>
Competition – Smother Crops
Practical applications of cover crops

Species and systems for the Mid-Atlantic Region
Reasons to Cover Crop

- Soil improvement, Soil health
  - Organic matter, structure/tilth, nutrient holding capacity, soil health
- Nutrient cycling
- Nitrogen source with legumes
- Ground cover or mulch
  - Erosion control, weed management, moisture management
- Pest management
What are your goals?

- Soil improvement/better yields
- N Scavenging
- Erosion control
- Mulch for no-till
- N source for corn
- N source for vegetables
- Nematode management
- Permanent/reseeding cover
- Other?
Cover crops for soil improvement
Economics

- Short term
  - Reduced inputs – N, herbicide, pesticides, other

- Long term
  - Soil improvement $?
    - Yield increase
    - Yield stability
  - Erosion control $?
  - Soil health and pest management $?
Using cover crops

- Winter annuals
- Summer annuals
- Perennials
- Covers
- Mulches
- Catch Crops
- Green Manure
- N sources
Systems and Tillage

- Cover tilled in - conventional
- Mulch systems – No-till
- Reseeding cover with no-till
- Permanent/perennial cover with no-till or with perennial crops
Mulch systems – managing cover

- Standing
- Mechanical kill
  - Mow
  - Chop
  - Roll/crush
- Non selective herbicides
- Low rate selective herbicides
- High rate selective herbicides
- Strip till with banded herbicide
- Heavy “Buffalo” cultivator
Cover Crops, Ground Cover, Erosion Control, Nutrient Recycling
Biomass - Mulch

[Image of agricultural field with rows of plants]

[Image of tractor in a field with mulch]

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Biotillage, Biodrilling, Root Zone Effects

- Rapeseed
- Rye
- Crimson clover
Brassicaceae
Competition – Smother Crops
Spring Cover Crops

- Frost Seeded Clovers
- **Spring Oats**
- Ryegrasses
- Mustards
- Field peas
- Bell Beans
- Radishes
- Turnips
- Other Brassicas
Summer Cover Crops

- **Grasses**
  - **Sorghum Species**
    - Sudangrass
    - Sorghum x Sudangrass
    - Forage Sorghums
  - Millets
    - Forage Pearl Millet
    - Foxtail, Japanese
    - Teff

- **Legumes**
  - Forage Soybeans
  - Cowpeas
  - Sun Hemp
  - Annual Lespedeza
  - Medics

- **Others**
  - Buckwheat
Fall Cover Crops

- Mustards
- Forage turnips
- Kales
- Hybrid Brassicas
- Forage/Daikon radishes
- Oilseed radishes
- Spring Oats
- Ryegrasses
- Bell beans
Overwintered Cover Crops

- Grasses
  - Small Grains
    - Rye
    - Triticale
    - Wheat
    - Barley
    - Winter Oats
  - Ryegrasses
- Legumes
  - Hairy Vetch
  - Crimson Clovers
  - Sub Clover
  - Winter Peas
  - Other clovers
- Brassicas
  - Rapeseed, Canola
  - Some Kales
  - Some Turnips and Mustards
  - Some Hybrids
Winter Killed Cover Crops

- Spring Oats
- Radishes
- Some Mustards and Turnips
- Any summer legume or grass planted late summer
  - Sorghums
  - Forage soybeans
  - Sun Hemp
Winter Annual Legumes

- Seed 3-6 weeks ahead of frost (Aug-Oct)
- Fall growth (Sept-Dec)
- Winter “dormancy” (Dec-Feb)
- Spring jump (March-May)
- Flowering (April-May)
- Seed formation (May-June)
- Reseeding?
- Used ahead of spring planted crops for multiple purposes
Success with cover crops - inoculants
Multi-season/perennial legumes

- Late summer Aug-Sept
- Some fall growth Sept-Dec.
- Winter dormancy Dec-Feb.
- OR Frost seed Jan-March
- Spring growth
- Flower + seed May-June
- Re-growth
- Used in living mulch systems and ahead of late spring, summer, or fall planted crops
Cereals

- Late Summer to Mid-Fall seeded normally (exc. Oats)
- Rye, wheat, barley, Triticale, oats.
- Significant fall growth
- Dormancy, spring oats winterkill
- Late winter-Mid spring rapid growth
- Head out, flower, seed and mature in May-July

Most useful for winter nutrient recovery ahead of spring planted crops and erosion control. Make good mulch crops.
Other winter annual grasses

- Seed August – Nov
- Quick growth in fall
- Annual rye grasses, bluegrasses, bromes, fescues
- Winter dormant
- Spring jump
- Head and seed in late spring.
- Used as catch crops, erosion control, and soil improvement ahead of spring planted field crops and vegetables
- Spring seeding ahead of summer vegetable crops
Ryegrass

- Other common name: Italian Ryegrass
- Winter-annual grass
- Introduced from Europe
- Many ryegrass cvs available such as Marshall
- Overseeded for pasture in the south
- Does well on heavy, waterlogged soils
- About 36-48" tall
- Biomass about 4,700-8,500 lb/acre
- N content about 1.3%
- Flowers May-June
- Often volunteers
- Plant 10-60 lbs/a (30-35)
- Catch crop, soil improvement, erosion control, and mulch crop
Perennial grasses – Cool season

- Seed August – Nov
- Low-moderate fall growth
- perennial ryegrasses, bluegrasses, bromes, fescues, orchardgrass
- Winter dormant
- Spring growth
- Head and seed in late spring.
- Used as catch crops, erosion control, and soil improvement ahead of late spring-summer planted field crops and vegetables. Used in permanent crop situations such as orchards
Summer annual grasses

- Plant in mid-late spring
- 6-12 weeks to flower
- Used as summer catch crops, green manure and mulch for fall crops
- Millets, sudangrass, sorghums
Warm season perennial grasses

- Established in late spring from seed or sprigs
- Useful for perennial systems needing summer cover
- Overseed with ryegrass for winter cover
- Bermudagrass, native grasses (such as bluestems), switchgrass
Annual legumes

- Late spring seeded
- Green manure or mulch crops
- N source
- Lespedeza, soybeans, cowpeas, mungbeans
- Sunhemp
Other annual Broadleaves

- Diverse species from cruciferae to amaranths
- Both winter and summer species
- Quick growth
- Green manure, catch crops, disease suppression, weed suppression
Legume-grass mixtures often perform better than either alone.
Rye and Hairy vetch are the king and queen of cover crops in the region.
Mid-Atlantic hairy vetch systems

- corn
- vine crops
- tomatoes
- other vegetables

- Alone or with rye and or crimson clover
Hairy vetch system details

- Seed 3-6 weeks ahead of frost date
- 15-30 lbs/a (20-25)
- May be combined with 30-60 lbs. rye and crimson clover 8-12 lbs.
- Drill, or broadcast into standing crop
- Use early flowering varieties for May planted crops (AU Early Cover, AU Merit)
- Herbicide treat when in flower – for corn 2,4-D, other crops 2 apps. of Gramoxone or Roundup.
- Roll kill is a viable option at flower
- No-till seed or transplant into killed Vetch.
- Additional residual preemerge herbicides can be used
Rye as a cover crop

- Rye for nutrient recovery
- Rye as a mulch
- Rye in field crop systems
- Rye in vegetable systems
Successful Mid-Atlantic Cover Crops

- Hairy Vetch to corn or sorghum
- Vetch to late vegetables
- Rye to corn or soybeans
- Rye to vegetables
- Wheat/barley to corn, soybeans, or vegetables
- Crimson clover to corn
- Field peas to corn
- Rye+Crimson to corn
- Rye+Vetch to corn or vegetables
- Rye+Vetch+Crimson to vegetables or corn
- Spring oats winter kill to early vegetables
- Ryegrass to corn, soybeans, or vegetables
- Crownvetch/Trefoil perennial cover with corn
- Subclover to corn or vegetables
Field crop rotations

- Corn-rye; FS Soybeans-rye
- Corn-rye; FS Soybeans-vetch
- Corn; wheat-DC Soybeans-overseed vetch
  - Can substitute crimson clover for vetch in all 3
- Irrig. Corn-os vetch; Irrig Corn-rye; FS soybeans os vetch (or wheat DC Soybeans os vetch)

Cover crop legume substitutes – crimson clover, field pea, sub clover, others?

Rye substitute – triticale, wheat, barley, ryegrass, Others?
Systems incorporating grazing

- Rye fall and spring graze to field crops or vegetables
- Rye plus crimson clover spring graze to field crops
- Ryegrass fall and spring graze to field crops
- Rye plus other winter legumes spring graze to field crops
PSU Living mulch system

Birdsfoot trefoil and Crownvetch living mulch
Crimson Clover

- Cool-season annual legume
- 12-20" tall
- Biomass 4,500-5,000 lb/a
- N content 2.4%
- Flowers April-May
- Matures May-June
- Taproot
- Plant 10-30 lbs/a
- Versatile in cropping systems in the mid-Atlantic
Winter Field peas

- Winter-annual legume
- Native to Europe, North Africa, or Western Asia
- 'Early Austrian', 'Dixie Wonder', 'Magnus', Melrose, Granger and 'Miranda'.
- Flowers early March-May
- Seed mature mid-April-June
- 'Austrian Winter' pea attains a height of 26" in monoculture; 'Magnus' is taller
- Biomass 6,000-8,500 lb/acre
- N content about 3-4%
- Used as cover crop in rotation with vegetable and field crops
- Does not re-establish itself: requires annual reseeding
- Plant 50-90 lbs/a
Spring Field Peas

- Annual Legume
- Same as Dried Peas – also called Canadian Field Peas
- Trapper a common variety
- Flowers early May-June
- Seed in March-April
- Biomass 6,000-8,500 lb/acre
- N content about 3-4%
- Used as cover crop in rotation with vegetable and field crops
- Used as a forage
- Plant 140 lb/ac or 120 lb/ac plus 20 lb/ac oats
Subterranean Clover

- Cool-season annual legume
- 6-15" tall
- Biomass is about 5,000 to 9,600 lb/a
- N content 2.3%
- Flowers April-May
- Matures May-June
- Self-reseeding
- Many cvs available with varying heights and maturity dates.
- Tolerates low fertility and low pH
- Used as a living or dying mulch with vegetables
- Plant 12-20 lbs/a
Red Clover

- Short-lived, perennial legume.
- Late summer or winter frost seeding
- **Seed** 10-15 lbs./A
- Many varieties
- Best used for late summer/fall crops or as a plow-down in mid spring
White clover

- (Dutch White Clover, New Zealand White Clover, Ladino Clover)
- *Trifolium repens*
- Perennial legume
- Many forms
- Flowers from April to December
- Height 8-10"
- Biomass production per year is about 11,100-22,200 lb/acre
- N content 2%
- Plant 3-7 lbs/acre
- Useful in permanent cover systems
- Hairy Vetch 80-250 lbs/a
- Crimson clover 50-130
- Field peas 50-150
- Red clover 60-110
- Sub clover 30-90
- White clover 80-100

- Berseem clover 90-250
- Sweetclover 50-100
- Bigflower vetch 30-90
- Black medic 30-60
Cover Crops, Living Mulches, and Roll Kill Mulch Systems in Vegetable Production

John R. Teasdale
USDA-ARS Sustainable Agricultural Systems Lab
Beltsville, MD

January 7, 2008
Hairy Vetch Mulch

(Vicia villosa)

- Alternative vegetable production system
- Improves soil quality
- Eliminates the need for polyethylene mulch
- Reduces required fertilizer N, herbicide, and pesticide inputs
- More profitable
System for Tomatoes in Hairy Vetch

September: • Prepare beds  
           • Plant hairy vetch

May:     • Mow or roll vetch  
         • Transplant tomatoes  
         • Lay drip tubes for irrigation/fertilizer

June:    • Stake  
         • Apply herbicide to kill vetch regrowth or control weeds
Vetch-grown tomato plants accumulate gene transcripts that enhance
• disease suppression and
• delayed senescence

(Mattoo et al.)
Rolling cover crops... or the quest for high surface residue levels
Weed Suppression with Cover Crop Residue
Living Mulch = Growing a cover crop at the same time as the cash crop

Problem: Any living mulch capable of competing with weeds will also compete with the crop.
Approaches to regulating living mulches

- Non-lethal herbicide
- Banded herbicide
- Strip tillage
- Mowing
- Supplemental irrigation/nutrients
- Reduced row spacing/increased population
- Relay planting
- Intercropping cash crops
Current Project – Biological Strip Till for Watermelons
Cover crops, soil building rotations and long-term no-till.

Gordon Johnson, University of Delaware Cooperative Extension
# Cover Crops – Why?

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Reduce soil erosion</td>
<td>Must be planted when time (labor) is limited</td>
</tr>
<tr>
<td>Increase residue cover</td>
<td>Additional costs (planting and killing)</td>
</tr>
<tr>
<td>Increase water infiltration into soil</td>
<td>Reduce soil moisture</td>
</tr>
<tr>
<td>Increase soil organic carbon</td>
<td>May increase pest populations</td>
</tr>
<tr>
<td>Improve soil physical properties</td>
<td>May increase risks of diseases</td>
</tr>
<tr>
<td>Improve field trafficability</td>
<td>Difficult to incorporate with tillage</td>
</tr>
<tr>
<td>Recycle nutrients</td>
<td>Allelopathy</td>
</tr>
<tr>
<td>Legumes fix nitrogen</td>
<td></td>
</tr>
<tr>
<td>Weed control</td>
<td></td>
</tr>
<tr>
<td>Increase populations of beneficial insects</td>
<td></td>
</tr>
<tr>
<td>Reduce some diseases</td>
<td></td>
</tr>
<tr>
<td>Increase mycorrhizal infection of crops</td>
<td></td>
</tr>
<tr>
<td>Potential forage harvest</td>
<td></td>
</tr>
<tr>
<td>Improve landscape aesthetics</td>
<td></td>
</tr>
</tbody>
</table>
### Example of Practices-Soil Properties Matrix

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Manure</th>
<th>Compost</th>
<th>Cover Crops</th>
<th>Tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>increase</td>
<td>increase</td>
<td>decrease</td>
<td>No effect</td>
</tr>
<tr>
<td>Available nutrients</td>
<td>increase</td>
<td>decrease</td>
<td>Mixed effects</td>
<td>Mixed effects</td>
</tr>
<tr>
<td>Total and active C</td>
<td>increase</td>
<td>increase</td>
<td>neutral</td>
<td>Decrease</td>
</tr>
<tr>
<td>Water holding capacity</td>
<td>increase</td>
<td>increase</td>
<td>increase</td>
<td>Depends</td>
</tr>
<tr>
<td>Aggregate stability</td>
<td>increase</td>
<td>increase</td>
<td>increase</td>
<td>Decrease</td>
</tr>
</tbody>
</table>
Cost Share Programs

- Cover Crop – Conservation Districts
- Long Term No-Till – NRCS, EQUIP
- Long Term No-Till – NRCS, CSP
- Other possibilities – NRCS, AMA
Economics

- Nitrogen from legumes
- Crop yield improvement
- Cover crop harvest?
  - Forage
  - Biomass
- Government payments
- Other?
Table 1. Average biomass yields and nitrogen yields of several legumes (4).

<table>
<thead>
<tr>
<th>Cover Crop</th>
<th>Biomass</th>
<th>Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet clover</td>
<td>1.75</td>
<td>120</td>
</tr>
<tr>
<td>Berseem clover</td>
<td>1.1</td>
<td>70</td>
</tr>
<tr>
<td>Crimson clover</td>
<td>1.4</td>
<td>100</td>
</tr>
<tr>
<td>Hairy vetch</td>
<td>1.75</td>
<td>110</td>
</tr>
</tbody>
</table>

Table 2. Percent nitrogen in legume tops and roots (6).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Tops % N</th>
<th>Roots % N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybeans</td>
<td>93</td>
<td>7</td>
</tr>
<tr>
<td>Vetch</td>
<td>89</td>
<td>11</td>
</tr>
<tr>
<td>Cowpeas</td>
<td>84</td>
<td>16</td>
</tr>
<tr>
<td>Red clover</td>
<td>68</td>
<td>32</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>58</td>
<td>42</td>
</tr>
</tbody>
</table>

Table 7. Nitrogen fertilizer replacement value of legume cover crops.

<table>
<thead>
<tr>
<th>Cover Crop</th>
<th>N replacement value (lbs/acre)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hairy vetch</td>
<td>80-89</td>
<td>Ebelhar, et al., 1984 (20)</td>
</tr>
<tr>
<td>Hairy vetch</td>
<td>170</td>
<td>Utomo, et al., 1990 (21)</td>
</tr>
<tr>
<td>Winter legumes</td>
<td>64-69</td>
<td>Hargrove, et al., 1986 (22)</td>
</tr>
<tr>
<td>Hairy vetch</td>
<td>110</td>
<td>McVay, et al., 1989 (23)</td>
</tr>
<tr>
<td>Crimson clover</td>
<td>88</td>
<td>McVay, et al., 1989 (23)</td>
</tr>
<tr>
<td>Winter legumes</td>
<td>75</td>
<td>Tyler, et al., 1987 (24)</td>
</tr>
<tr>
<td>Legume/non-legume crop</td>
<td>NFE (kg ha(^{-1}))</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-----------------------</td>
<td></td>
</tr>
<tr>
<td>Hairy vetch/cotton</td>
<td>67–101</td>
<td></td>
</tr>
<tr>
<td>Hairy vetch + rye/corn</td>
<td>56–112</td>
<td></td>
</tr>
<tr>
<td>Hairy vetch/corn</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Hairy vetch/sorghum</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>Hairy vetch/corn</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Hairy vetch + wheat/corn</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Crimson clover/cotton</td>
<td>34–67</td>
<td></td>
</tr>
<tr>
<td>Crimson clover/corn</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Crimson clover/sorghum</td>
<td>19–128</td>
<td></td>
</tr>
<tr>
<td>Common vetch/sorghum</td>
<td>30–83</td>
<td></td>
</tr>
<tr>
<td>Bigflower vetch/corn</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Subterranean clover/sorghum</td>
<td>12–103</td>
<td></td>
</tr>
<tr>
<td>Sesbania/allowland rice</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Alfalfa/corn</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Alfalfa/wheat</td>
<td>20–70</td>
<td></td>
</tr>
<tr>
<td>Arachis spps/wheat</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Subterranean clover/wheat</td>
<td>66</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5. Crop yield and net return for the four management systems during the 6-yr period of the study.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>Corn</td>
<td>8,625</td>
<td>8,563</td>
<td>9,125</td>
<td>8,250</td>
<td>8,375</td>
<td>7,938</td>
<td>8,500</td>
</tr>
<tr>
<td>A2</td>
<td>Corn</td>
<td>8,500</td>
<td>9,313</td>
<td>9,250</td>
<td>6,938</td>
<td>9,500</td>
<td>7,875</td>
<td>8,563</td>
</tr>
<tr>
<td>B</td>
<td>Corn</td>
<td>9,375</td>
<td>11,000</td>
<td>10,188</td>
<td>8,625</td>
<td>9,875</td>
<td>8,500</td>
<td>9,563</td>
</tr>
<tr>
<td>C</td>
<td>Corn</td>
<td>8,375</td>
<td>9,438</td>
<td>10,750</td>
<td>7,625</td>
<td>8,500</td>
<td>8,750</td>
<td>8,938</td>
</tr>
<tr>
<td>D</td>
<td>Corn</td>
<td>9,438</td>
<td>8,813</td>
<td>8,500</td>
<td>7,563</td>
<td>8,625</td>
<td>6,375</td>
<td>8,250</td>
</tr>
<tr>
<td>SE&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>660</td>
<td>962</td>
<td>1,058</td>
<td>811</td>
<td>824</td>
<td>1,459</td>
<td>1,199</td>
</tr>
<tr>
<td>B</td>
<td>Soybean</td>
<td>4,333</td>
<td>4,667</td>
<td>3,133</td>
<td>3,800</td>
<td>3,600</td>
<td>3,600</td>
<td>3,867</td>
</tr>
<tr>
<td>D</td>
<td>Soybean</td>
<td>4,067</td>
<td>4,133</td>
<td>2,933</td>
<td>3,733</td>
<td>4,067</td>
<td>4,067</td>
<td>3,800</td>
</tr>
<tr>
<td>C</td>
<td>Double-cropped soybean</td>
<td>2,267</td>
<td>2,733</td>
<td>1,733</td>
<td>1,200</td>
<td>1,400</td>
<td>1,400</td>
<td>1,800</td>
</tr>
<tr>
<td>C</td>
<td>Wheat</td>
<td>4,800</td>
<td>4,267</td>
<td>1,467</td>
<td>5,667</td>
<td>4,000</td>
<td>3,667</td>
<td>4,467</td>
</tr>
<tr>
<td>D</td>
<td>Wheat</td>
<td>3,667</td>
<td>5,467</td>
<td>2,200</td>
<td>7,067</td>
<td>3,333</td>
<td>4,867</td>
<td>4,400</td>
</tr>
</tbody>
</table>

**Net return**<sup>c</sup> $ ha<sup>-1</sup>:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>52</td>
<td>242</td>
<td>252</td>
<td>101</td>
<td>−183</td>
<td>40</td>
<td>84</td>
</tr>
<tr>
<td>A2</td>
<td>−54</td>
<td>264</td>
<td>205</td>
<td>−106</td>
<td>−158</td>
<td>−27</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>257</td>
<td>630</td>
<td>415</td>
<td>331</td>
<td>101</td>
<td>−84</td>
<td>274</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>321</td>
<td>111</td>
<td>111</td>
<td>−106</td>
<td>−44</td>
<td>119</td>
</tr>
<tr>
<td>D</td>
<td>151</td>
<td>440</td>
<td>138</td>
<td>225</td>
<td>30</td>
<td>−109</td>
<td>146</td>
</tr>
</tbody>
</table>

<sup>a</sup> System A1 is continuous no-tillage corn; System A2 is continuous no-tillage corn with no-tillage planted rye cover crop; System B is reduced tillage corn rotated with no-tillage soybeans; System C is no-tillage corn followed by reduced tillage winter wheat followed by no-tillage double-cropped soybeans within a 2-yr rotation; and System D is a 3-yr rotation of no-tillage corn planted in vetch cover crop followed by fall planted rye cover crop, second year is no-tillage soybean, followed by reduced tillage winter wheat with vetch planted after wheat harvest. Systems A1, A2, and B relied upon a prophylactic approach to pest management. System C relied upon prescription (POST) weed control, and System D emphasized cultural and biological pest management with cultivation and reduced rate of POST herbicides where needed. See text for detailed description of tillage and pest management strategies.
Cropped soils will come to a steady state in the amount of organic matter they contain.
How Organic Matter is Lost

- Decomposition (oxidation)
- Microbial activity
- Heat, moisture
- Tillage
- Cropping systems
Generalized map of US showing SOM in tons per acre to 40 inches as related to climate and vegetation.
How Organic Matter is Accumulated

- Plant materials added (or animal materials)
- Additions outpace decomposition processes
- Slowed decomposition
- C:N ratio
- Accumulations of stable humus compounds
Cropping Practices That Increase Organic Matter

- Permanent crops
  - Pastures, hayfields
- Cropping systems
  - Cover crops
  - Green manures
  - Rotations
- Reduced tillage or no-till
  - Crop residue return
  - Long term no-till
- Additions
  - Manure
  - Compost
  - Other residue
Crop Rotation Effect on Soil Health

Examples

- Organic matter addition or loss
- Increase or decrease compaction
- pH changes
- Disease buildup or reduction
Soil Health, Cropping Systems, and Soil Born Disease Management

- Microbial diversity and diseases
  - Competitive displacement
  - Direct effects on pathogens
- Organic additions promoting diversity
- Cover crops, green manures, and, crop residue as food for microorganisms
- Cover crops and green manures as natural fumigants
Example - Trichoderma

- Mycoparasitism
- Antibiosis
- Competition for nutrients or space
- Tolerance to stress through enhanced root and plant development
- Solubilization and sequestration of inorganic nutrients
- Induced resistance
- Inactivation of the pathogen’s enzymes
Effects of Soil Management on Soil Organisms

Mary Barbercheck Dept. of Entomology
Penn State University
In 1 teaspoon of agricultural soil there are…

<table>
<thead>
<tr>
<th>Organism</th>
<th>Amount/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>100 million to 1 billion</td>
</tr>
<tr>
<td>Fungi</td>
<td>6-9 ft fungal strands put end to end</td>
</tr>
<tr>
<td>Protozoa</td>
<td>Several thousand flagellates &amp; amoeba</td>
</tr>
<tr>
<td></td>
<td>One to several hundred ciliates</td>
</tr>
<tr>
<td>Nematodes</td>
<td>10 to 20 bacterial feeders and a few fungal feeders</td>
</tr>
<tr>
<td>Arthropods</td>
<td>Up to 100</td>
</tr>
<tr>
<td>Earthworms</td>
<td>5 or more</td>
</tr>
</tbody>
</table>
The Soil Food Web

First trophic level: Photosynthesizers

Second trophic level: Decomposers, Mutualists, Pathogens, parasites, Root-feeders

Third trophic level: Shredders, Predators, Grazers

Fourth trophic level: Higher level predators

Fifth and higher trophic levels: Higher level predators

Plants
- Shoots and roots
- Mycorrhizal fungi
- Saprophytic fungi

Organic Matter
- Waste, residue and metabolites from plants, animals and microbes.

Fungi
- Fungal and bacterial-feeders

Nematodes
- Root-feeders
- Predators

Arthropods
- Shredders
- Predators

Protozoa
- Amoebae, flagellates, and ciliates

Bacteria

Animals

Birds
Some Goals of Soil Management

- Manage system for productivity and beneficial processes
- Improvement in abiotic and biotic properties of soil
- Improvement of plant health
- Conservation of beneficial organisms
- Suppression of pests
Crop Rotations
Know Your Pest
Reduce Pest Habitat
Provide Beneficial Habitat
Minimal Pesticide Use

Above-Ground Diversity to Favor Beneficials → Pest and Disease Suppression

Healthy Plants!

Healthy Soil
Below-Ground Diversity

Add Organic Matter
Crop Rotations
Minimize Tillage to Conserve OM
Minimal Use of Synthetic Pesticides & Fertilizers
Some Factors Affected by Tillage

- Soil Moisture
- Soil Temperature
- Range of Temperature and Moisture Fluctuations
- Surface Residue
- Soil Fauna Abundance and Diversity
- Plant Diversity
- Favors Bacteria > Fungi
BMP for Management of Soil Organisms

- Systems effects can arise from very complex direct and indirect interactions
- Minimize compaction
- Provide continuous energy (e.g., cover crops)
- Reduce tillage to favor fungal-based food webs
- Provide refuges for mobile predators
- Rotate crops to reduce pest organisms
- Reduce use of biocides

Cosmochthonius (Oribatida)

D. Walter
Cropping System Effect on Nutrient Cycling

- Nutrient uptake
- Rooting depth
- Living cover and nutrient interception
  - Winter cover
- N fixation
- Rate of mineralization of organic matter
Nitrogen Recovery With Winter Cover Crops

- N uptake when no crop would be present
- Early growth, tillering, soil cover
- Rooting depth
- Hardiness and winter growth activity
Cover Crops as Filters

- Slow Runoff
- Intercept nutrients
- Intercept soil
Cover Crops and Crop Production

- Return organic matter
- Recycle nutrients
- N from legumes
- Erosion control
- Weed suppression
- Moisture?
- Disease suppression?
Legumes in Rotation

- N fixation
- Mineralization rate
- Root structure
- Pest profile
Green Manures

- Used strictly for soil improvement
- Takes crop out of production for a period
- Organic matter
- Soil condition
- Biological activity
- Pest suppression
Organic Additions and Microbial Activity

- Organic matter increases biological activity
- Fresh vs. dry residue
- Moisture
- Temperature
- Toxic materials
Managing Rye as a Cover Crop
Cover crops, vegetable, and field crop rotations
No-Till Vegetables
Cover crops and Nitrogen
Cover crop timing
Weeds and cover crops