Carbon Farming vs. Farming for Carbon

How to improve soil organic matter

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“Although managing SOM is usually not a priority in farm decision making, practices that improve SOM contribute more than any other resource to a farm's long-term productivity”
Benefits of Soil Organic Matter:

- Reservoir of plant nutrients
- "Food" for soil biota
- Soil Physical properties
  - Reduces soil density
  - Essential for aggregate formation
  - Improves air/water infiltration
  - Improves water storage
- Improves soil "Tilth"
- Reduces soil erosion
Organic matter is 1-8% of total soil mass.

- **Stabilized Organic Matter (humus)**: 33-50%
- **Decomposing Organic matter (active fraction)**: 33-50%
- **Living organisms**: <5%
- **Fresh Residue**: <10%
Soil organic matter is composed of:

- Organic matter is the vast array of carbon compounds in soil.
- Originally created by plants, microbes, and other organisms,
- Plant materials consist of simple sugars, cellulose, hemicellulose and lignin – contain also proteins and amino sugars

Decay Process – solution, fragmentation, decay and humification.

Humification: Chemical process, condensation will N compounds and lignin.
Carbon Farming vs. Farming for Carbon?
Carbon Farming vs. Farming for Carbon?
From Verle Kaiser Archive, WSU
USDA-SCS, 1942
Soil Degradation: Farming Carbon

The downward spiral of soil degradation.

Adapted From Topp et al., 1995
Soil Type

Mollisol
Grasslands
6-8+%

Alfisol
Forests
4-6%

Aridisol
Columbia Basin
1-3%
Columbia Basin Soils Developed: Arid environment

Annual Precip. 6-8” (winter)
MAT 52 °F
Temp Range <32 - 110 °F
Sands - silt loam soils

Native Vegetation: Shrub-steppe
- big sagebrush (others)
- antelope bitterbrush
- rabbit brush
- bluebunch wheatgrass
- Idaho Fescue
- Sandberg’s bluegrass
- needle grass

Annual Residue Input
Shrub-steppe 1,100 lb ac\(^{-1}\)
Cultivated 3,000 – 12,000 lb ac\(^{-1}\)
### Major Crops of the Columbia Basin (WA)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acreage</th>
<th>Value per acre</th>
<th>Cost of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onions</td>
<td>18,000</td>
<td>$6,848</td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td>163,000</td>
<td>$3,019</td>
<td></td>
</tr>
<tr>
<td>Asparagus</td>
<td>12,400</td>
<td>$2,705</td>
<td></td>
</tr>
<tr>
<td>Carrots (process)</td>
<td>5,100</td>
<td>$2,040</td>
<td></td>
</tr>
<tr>
<td>Sugar beets</td>
<td>4,000</td>
<td>$1,425</td>
<td></td>
</tr>
<tr>
<td>Mint</td>
<td>37,500</td>
<td>$1,081</td>
<td></td>
</tr>
<tr>
<td>Alfalfa seed</td>
<td>12,500</td>
<td>$1,061</td>
<td></td>
</tr>
<tr>
<td>Silage Corn</td>
<td>52,900</td>
<td>$763</td>
<td></td>
</tr>
<tr>
<td>Sweet Corn</td>
<td>98,300</td>
<td>$705</td>
<td></td>
</tr>
<tr>
<td>Field Corn</td>
<td>74,300</td>
<td>$566</td>
<td></td>
</tr>
<tr>
<td>Peas (green)</td>
<td>34,300</td>
<td>$461</td>
<td></td>
</tr>
<tr>
<td>Grass seed</td>
<td>25,800</td>
<td>$461</td>
<td></td>
</tr>
<tr>
<td>Alfalfa/hay</td>
<td>174,000</td>
<td>$423</td>
<td></td>
</tr>
<tr>
<td>Beans</td>
<td>38,700</td>
<td>$326</td>
<td></td>
</tr>
<tr>
<td>Winter Wheat</td>
<td>82,000</td>
<td>$201</td>
<td></td>
</tr>
<tr>
<td>Spring Wheat</td>
<td>59,400</td>
<td>$144</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>892,200</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Source WAS, 2003**

- $2,000 – 2,500 acre
- $110 – 160 acre
“Increased frequency of tillage and low residue crops in rotation increases soil erosion”

Photos from Bob Thornton, 1970’s
Loss Due to Erosion

- Difficult to measure
- Offset by increased inputs
  - water
  - fertilizer
  - pesticides
  - labor
  - energy
  - improved genetics
Decline in Soil Organic Matter

Most organic matter losses in soil occurred in the first decade or two after land was cultivated. Native levels of organic matter may not be possible under agriculture, farmers can increase the amount of active organic matter by reducing tillage and increasing organic inputs.

- Increased residue return.
- Reduced tillage.
- Perennial Rotations.
  - Grass and alfalfa
- Cover crops
- Manure/Compost additions.
- Elimination of bare fallow.
Impact of Irrigated Ag on Soil Organic Carbon

Source: WADOE Report# 99-309
Rotation Effects on C-Storage

SOM Increase Over Monoculture (%) vs. Years of Cultivation

- Fallow
- Legume
- Cereals
- Grass/forage
- Pasture

The graph illustrates the rotation effects on carbon storage over monoculture. The x-axis represents the years of cultivation, while the y-axis shows the increase in SOM (Soil Organic Matter) over monoculture as a percentage. Different symbols indicate various rotational practices, with each showing a trend over time.
SOM Formation: Residue Decomposition

Decomposition/Mineralization

Crop residue → CO₂, CH₄

DOC → CO₂

SOM Formation: Residue Decomposition

Weeks of Decomposition

Percent of Residue Remaining

- Leaves CT
- Stems CT
- Leaves NT
- Stems NT

SOIL

Nutrient availability

Soil disturbance

Decomposer community

Rotational crops

Soil Tilth

Controls

Erosion

Weeks of Decomposition

0 10 20 30 40

Percent of Residue Remaining

0

20

40

60

80

100

Leaves CT

Stems CT

Leaves NT

Stems NT

SOM Contents:

Residue Decomposition

Abiotic (T, H₂O, O₂, pH)

Substrate Attributes

- chemical
- physical

DOC

CO₂
Conservation tillage is a system that “manages the amount, orientation, and distribution of crop and other plant residues on the soil surface”.

At least 30% of the soil surface is covered with crop residue immediately following planting.

- Conservation tillage is an “umbrella” term for many tillage systems that are called by many different names. Commonly used are no-till, direct-seed, strip-till, ridge-till, and mulch-till.

- The goal of these systems is to maintain sufficient residue on the soil surface to reduce wind and water erosion, reduce energy use, conserve soil and water resources, reduce costly inputs and improve profits.
This 1914 photo shows that no-tilling wheat after soybeans is not a new idea.

JC Allin and Sons Inc/Rural Life
Benefits of Conservation Tillage Systems

**Saves:**
- Labor & Time ($2.70/ac)
- Fuel (3.5 gal/ac)
- Machinery wear ($5/ac)

**Increases:**
- Soil OM (10-20%)
- Wildlife

**Improves:**
- Soil Tilth
- Soil Moisture and Infiltration
- Water Quality
- Air Quality

**Reduces:**
- Soil Erosion (≥ 90%)
No-till potatoes 1977
WSU
This strategy reduced the total number of passes in the potato crop from eleven to seven and soil disturbance operations from seven to three, compared to those used in conventional tilled treatments. In season fertilizer and pesticides were aerial or through center pivot irrigation.

The shoes of the planter periodically would drag residues deforming the hills, decreasing corn residue size by flail chopping residues is necessary.

Reduced till sweet corn was direct seeded reducing tillage operations 100% in year 2 of the three year rotation.
# Effect of Tillage on Potato and Sweet corn yields.

**Three yr rotation: SWC-SWC-P**

<table>
<thead>
<tr>
<th>Year</th>
<th>Potato</th>
<th>Sweet Corn yr1</th>
<th>Sweet Corn yr2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>CT</td>
<td>CT</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>RT</td>
<td>RT</td>
</tr>
<tr>
<td>2001*</td>
<td>33.5</td>
<td>10.2</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td>32.1</td>
<td>8.8</td>
<td>8.8</td>
</tr>
<tr>
<td>2002*</td>
<td>32.6</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>32.5</td>
<td>7.4</td>
<td>6.7</td>
</tr>
<tr>
<td>2003</td>
<td>33.1</td>
<td>†4.5</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>31.2</td>
<td>4.1</td>
<td>4.4</td>
</tr>
<tr>
<td>2004</td>
<td>27.8</td>
<td>9.9</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>27.0</td>
<td>10.4</td>
<td>9.4</td>
</tr>
<tr>
<td>2005</td>
<td>37.7</td>
<td>12.5</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>38.6</td>
<td>10.2</td>
<td>7.0</td>
</tr>
<tr>
<td>2006</td>
<td>36.3</td>
<td>11.5</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>36.1</td>
<td>10.4</td>
<td>9.0</td>
</tr>
<tr>
<td>2007</td>
<td>31.0</td>
<td>12.0</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td>30.9</td>
<td>10.6</td>
<td>9.4</td>
</tr>
<tr>
<td>2008</td>
<td>40.9</td>
<td>13.5</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>39.7</td>
<td>13.2</td>
<td>9.7</td>
</tr>
<tr>
<td>Average</td>
<td>34.1&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>11.0</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>33.5&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>10.1</td>
<td>8.6*</td>
</tr>
</tbody>
</table>

Potato variety – Ranger Russet. † Field Corn. (150-180 bu/ac).
Reduction of tillage maintains crop residues

• Creates changes in soil biological, chemical and physical properties
  - not independent of one another

• Simplest change in physical condition is due to a “dilution effect”

• Increase in SOM

• Stimulate Microbial Activity
  - Increased respiration and biomass.
  - Production of polysaccharides and mucigels bind soil particles together.
  - Increase of fungal hyphae further bind small aggregates into large aggregates.
Properties of Soils: Influenced by tillage

Reduced tillage

- SOM ↑
- Soil temperature ↓
- Bulk density ↓
- Aggregation and Aggregate Stability ↑
- Total Porosity - pore size distribution ↑
- Soil resistance to penetration ↓
- Water Infiltration ↑
- Water holding capacity and retention ↑
- Microbial populations ↑
Where do changes occur?

Changes under reduced tillage/or high residue farming typically occur in the surface 3-4 inches of soil.
Tillage Effects on C-Storage

% SOM Increase (NT-CT)/CT vs Years of Cultivation

-20 0 20 40 60

Years of Cultivation

0 5 10 15 20 25 30 35

Tillage Effects on C-Storage
Building SOM with Organic Amendments

Types of Soil Organic Amendments

• On farm wastes:
  - manure, crop residues, spoiled straw, hay and silage

• Municipal wastes:
  - yard debris, and biosolids (sewage sludge)

• Organic wastes from food processors:
  - vegetable, meat, fish, dairy

• Organic wastes from paper mills and timber industry:

• Composts

• Other? Humic/Fulvic Acids
Maintaining residues builds SOM:

- Reservoir of plant nutrients
- “Food” for soil biota
- Soil Physical properties
  - Reduces soil density
  - Essential for aggregate formation
  - Improves air/water infiltration
  - Improves water storage
- Improves soil “Tilth”
- Reduces soil erosion
Input of Organic Amendments

• Creates changes in soil biological, chemical and physical properties
  - not independent of one another

• Simplest change in physical condition is due to a “dilution effect”

• Stimulate Microbial Activity
  - Increased respiration and biomass.
  - Production of polysaccharides and mucigel bind soil particles together.
  - Increase of fungal hyphae further bind small aggregates into large aggregates.
Organic Amendments and their C:N ratios.

<table>
<thead>
<tr>
<th>Organic amendment</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td>High in carbon</td>
<td></td>
</tr>
<tr>
<td>Corn stalks</td>
<td>60-70</td>
</tr>
<tr>
<td>Straw</td>
<td>40-150</td>
</tr>
<tr>
<td>Corn silage</td>
<td>40</td>
</tr>
<tr>
<td>Fall leaves</td>
<td>30-80</td>
</tr>
<tr>
<td>Sawdust</td>
<td>200-700</td>
</tr>
<tr>
<td>Brush, wood chips</td>
<td>100-500</td>
</tr>
<tr>
<td>Bark (paper mill waste)</td>
<td>100-130</td>
</tr>
<tr>
<td>Newspaper</td>
<td>400-800</td>
</tr>
<tr>
<td>Cardboard</td>
<td>500</td>
</tr>
<tr>
<td>Mixed paper</td>
<td>150-200</td>
</tr>
<tr>
<td>High in Nitrogen</td>
<td></td>
</tr>
<tr>
<td>Hay</td>
<td>15-30</td>
</tr>
<tr>
<td>Dairy manure</td>
<td>5-25</td>
</tr>
<tr>
<td>Poultry manure</td>
<td>5-15</td>
</tr>
<tr>
<td>Hog manure</td>
<td>10-20</td>
</tr>
<tr>
<td>Cull potatoes</td>
<td>18</td>
</tr>
<tr>
<td>Vegetable wastes</td>
<td>10-20</td>
</tr>
<tr>
<td>Coffee grounds</td>
<td>20</td>
</tr>
<tr>
<td>Grass clippings</td>
<td>15-25</td>
</tr>
<tr>
<td>Municipal biosolids</td>
<td>9-25</td>
</tr>
</tbody>
</table>

Cooperband, 2002
## Average nutrient content from manures

<table>
<thead>
<tr>
<th>Type of Manure</th>
<th>N</th>
<th>P$<em>{2}$O$</em>{5}$</th>
<th>K$_{2}$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy, solid</td>
<td>10</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Beef, solid</td>
<td>14</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Swine, solid</td>
<td>14</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Duck, solid</td>
<td>17</td>
<td>21</td>
<td>30</td>
</tr>
<tr>
<td>Chicken, solid</td>
<td>40</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Turkey, solid</td>
<td>40</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Sheep, solid</td>
<td>26</td>
<td>18</td>
<td>40</td>
</tr>
<tr>
<td>Horse, solid</td>
<td>10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Dairy, liquid</td>
<td>24</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Veal calf, liquid</td>
<td>15</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Beef, liquid</td>
<td>20</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Swine, liquid indoor pit</td>
<td>50</td>
<td>42</td>
<td>30</td>
</tr>
<tr>
<td>Swine, liquid outdoor pit</td>
<td>34</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Swine, liquid, farrow-nursery indoor pit</td>
<td>25</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>Poultry, liquid</td>
<td>16</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

Cooperband, 2002
## Residue Nutrient Content

<table>
<thead>
<tr>
<th></th>
<th>Wheat</th>
<th>Corn</th>
<th>Potato</th>
<th>Peas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>8-12</td>
<td>15-30</td>
<td>30-40</td>
<td>25-30</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>3-5</td>
<td>3-5</td>
<td>6-12</td>
<td>5-6</td>
</tr>
<tr>
<td>Potassium</td>
<td>27-40</td>
<td>30-50</td>
<td>80-120</td>
<td>30-35</td>
</tr>
<tr>
<td>Sulfur</td>
<td>2-3</td>
<td>2-3</td>
<td>4-8</td>
<td>5-6</td>
</tr>
<tr>
<td>Calcium</td>
<td>4-5</td>
<td>4-8</td>
<td>12-25</td>
<td>3-4</td>
</tr>
<tr>
<td>Magnesium</td>
<td>2-3</td>
<td>3-5</td>
<td>8-20</td>
<td>2-3</td>
</tr>
</tbody>
</table>
Cover Crop:

“Any crop grown primarily to provide ground cover to improve soil properties, rather than providing a harvestable yield”.

Cover crops include:

- Legumes (vetch, clovers, peas)
- Small grains (Rye, triticale, wheat)
- Sudan grass
- Brassica’s (mustard, arugula)
Historical Timeline of Cover Crops in Columbia Basin

1950’s-60’s
- Wind erosion control
- N supply with legumes
1970’s-80’s
- Weed, disease, nematode suppression
1990’s
- Nitrate recovery and recycling
Benefits of Cover Crops

Enhance Soil Structure

Cover Crops

Environmental Quality

- Increased Soil Biota
- Increased Nutrient Cycling
- Increased pH Buffering

Cover Crops

- Improved Aggregation
- Improved Aeration
- Improved Infiltration

Cover Crops

- Weed Suppression
- Pathogen Suppression
- Nematode Suppression

Cover Crops

Environmental Quality

- Reduced Run-off
- Reduced Erosion
- Reduced N-leaching

Cover Crops

Environmental Quality

- Improved Pest Management
How Cover Crops/Green Manures Work to Reduce Disease:

• **Crop rotation**
  - Changes field conditions
  - Increase diversity of crops

• **Competitive Exclusion**
  - Competition Resources
  - Energy
  - Space
  - Nutrients

• **Biofumigation**
  - Glucosinolates + enzymes
  - ITCs

• **Antagonism/Predation**
Soil Community Response to Cover Crops:

**Bio-fumigation: Brassicas/Sudangrass/Vetch**
- inhibit *Verticillium dahliae* on potato
- suppresses *Columbia* root-knot nematode
- reduces incidence of black root rot of cotton
- reduces incidence of corky root of tomato

**Increases the predation and feeding of:**
- **Free-living nematodes**
  - *Fusarium, Rhizoctonia, root knot cyst nematode*
- **Collembola**
  - *Rhizoctonia solani, Pythium*
- **Mites**
  - *Rhizoctonia*
Other Responses:

*Increase microbial and fungal populations:*
  - *Competition and/or suppression*
    - Non-pathogenic vs Pathogenic (Fusarium)
    - Pasteuria penetrans vs nematodes
  - *Direct Antagonism*
    - Pythium vs Psuedomonas spp.
  - *Production of hormones, antibiotics*
    - Protozoa produce auxins
    - siderophores
Conservation Tillage Creates Habitat Shift

Biological Diversity Increases

Microflora  Microfauna  Macrofauna  Insects  Animals
Ratio of Microbial Populations between no-till and conventional till.

<table>
<thead>
<tr>
<th>Microbial Group</th>
<th>0-3 in.</th>
<th>3-6 in.</th>
<th>0-6 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Aerobes</strong></td>
<td>1.35***</td>
<td>0.71***</td>
<td>1.03</td>
</tr>
<tr>
<td><strong>Fungi</strong></td>
<td>1.57***</td>
<td>0.76**</td>
<td>1.18</td>
</tr>
<tr>
<td><strong>Actinomycetes</strong></td>
<td>1.14***</td>
<td>0.98</td>
<td>1.08</td>
</tr>
<tr>
<td><strong>Aerobic bacteria</strong></td>
<td>1.41***</td>
<td>0.68***</td>
<td>1.03</td>
</tr>
<tr>
<td><strong>NH₄ oxidizers</strong></td>
<td>1.25*</td>
<td>0.55**</td>
<td>0.89</td>
</tr>
<tr>
<td><strong>NO₃ oxidizers</strong></td>
<td>1.58*</td>
<td>0.75**</td>
<td>1.14</td>
</tr>
<tr>
<td><strong>Facultative Anerobes</strong></td>
<td>1.57*</td>
<td>1.23</td>
<td>1.32*</td>
</tr>
<tr>
<td><strong>Denitrifiers</strong></td>
<td>7.31*</td>
<td>1.77</td>
<td>2.83</td>
</tr>
</tbody>
</table>

Doran et. al., 1993
### Influence of residues and reduced tillage on plant disease

#### Table 1. Field and sweet corn diseases.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen lives in</th>
<th>Trend/w reduced till</th>
<th>Rotation interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed rot</td>
<td>Res./soil</td>
<td>unknown</td>
<td>1-2 yr</td>
</tr>
<tr>
<td>Stalk rot</td>
<td>Res./soil</td>
<td>unknown</td>
<td>1-2 yr</td>
</tr>
<tr>
<td>Smuts</td>
<td>Soil/plant</td>
<td>NC</td>
<td>NA</td>
</tr>
<tr>
<td>HPV</td>
<td>Mite</td>
<td>NC</td>
<td>NA</td>
</tr>
<tr>
<td>MDV</td>
<td>Aphid</td>
<td>NC</td>
<td>NA</td>
</tr>
</tbody>
</table>

#### Table 2. Wheat diseases.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen lives in</th>
<th>Trend/w reduced till</th>
<th>Rotation interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root rot</td>
<td>Res./soil</td>
<td>Decrease</td>
<td>2-3 yr</td>
</tr>
<tr>
<td>Pythium</td>
<td>Res./soil</td>
<td>NC</td>
<td>3-4 yr</td>
</tr>
<tr>
<td>Ceph. stripe</td>
<td>Res./soil</td>
<td>Varies</td>
<td>2-3 yr</td>
</tr>
<tr>
<td>Take-all</td>
<td>Residue</td>
<td>Varies</td>
<td>1-2 yr</td>
</tr>
<tr>
<td>Leaf Spot</td>
<td>Residue</td>
<td>Increase</td>
<td>1-2 yr</td>
</tr>
<tr>
<td>Rusts</td>
<td>plants</td>
<td>NC</td>
<td>NA</td>
</tr>
<tr>
<td>Smut</td>
<td>Seed</td>
<td>NC</td>
<td>NA</td>
</tr>
<tr>
<td>Bunt</td>
<td>Soil/seed</td>
<td>NC</td>
<td>NA</td>
</tr>
</tbody>
</table>

#### Table 3. pulses (peas, beans, lentils).

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen lives in</th>
<th>Trend/w reduced till</th>
<th>Rotation interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascochyta</td>
<td>Res./seed</td>
<td>Increase</td>
<td>2 yr</td>
</tr>
<tr>
<td>Sclerotinia</td>
<td>Soil</td>
<td>Decrease</td>
<td>3+ yr</td>
</tr>
<tr>
<td>Anthracnose</td>
<td>Res./seed</td>
<td>Increase</td>
<td>3-4 yr</td>
</tr>
<tr>
<td>Damping off</td>
<td>Res./soil</td>
<td>Increase</td>
<td>3+ yr</td>
</tr>
<tr>
<td><em>Botrytis</em> rot</td>
<td>Res./seed</td>
<td>Increase</td>
<td>2-3 yr</td>
</tr>
<tr>
<td>Powdery mildew</td>
<td>Residue</td>
<td>NC</td>
<td>3-4 yr</td>
</tr>
</tbody>
</table>

NC-No change, NA- Not applicable. From Krupinsky, et al., 1997.
Potatoes & other root crops have more soil disturbance and trips across the field resulting in compaction. Increased frequency of tillage increases soil compaction.

Soil Compaction:

Compaction is a major source of yield reduction.

- Restricts root growth.
  - limits water availability
  - limits nutrient availability
- Limits aeration.
  - poor root health
  - increased root pathogens
- Limits tuber growth.

[Graph showing the relationship between bulk density and total yield]
Stimulation of the soil microflora: Changes in Nutrient Cycling: Increases immobilization of N, P, S, etc.
Relationship between bulk density and organic matter content

Deceases in BD due to:
- dilution effect
- aggregation
- increased porosity
Relationship between aggregate stability and organic matter content.

- Kay and Angers (1999) found that a minimum of 2% SOM was needed to maintain structural stability. If SOC was < 1.5% stability rapidly declines.

- Boix-Fayos (2003) found that 3-3.5% SOM was needed to increase aggregate stability.

From Chaney and Swift, 1984
Summary: Successful Adoption

Change perspective on how a field should look.
Change perspective on how crops are managed.
Determine system that works for each producer.
System will have to be fine tuned to fit:

- soils
- growing conditions
- grower management abilities
- different crop varieties
- longer rotations, crop selections.

- Cropping system choices impact weed related issues in production.
Resources:

- The Soil Biology Primer, SWCS. www.swcs.org
- Sustainable Agriculture Research and Education Program. www.sare.org
- ATTRA – Appropriate Technology Transfer for Rural Areas. www.attra.org
- WSU Crop and Soil Sciences. www.wsu.edu