Linking Fruit and Soil Quality (Health)

Preston Andrews, Ph.D. Horticulture

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Pasco, Washington
Overview

• Definitions of fruit & soil quality (health)
• Historical perspective of emphasis on inorganic over organic fertilizers
• “Living soil” - carbon & nitrogen cycles
• Three studies: Apple, strawberry & tomato
• Characteristics of “living soil” & conclusions
Fruit quality
Standards that distinguish fruit as superior

- size
- color
- firmness
- sugars & acids
- dry matter & water content
- sensory (sweetness, tartness, texture, aroma, flavor)
- nutritional value (vitamins, minerals, phytochemicals)
- keeping qualities (storage, shelf-life, etc.)
Soil quality (health)

“...capacity of a soil to function within ecosystem boundaries (limits, capacity) to sustain biological productivity, maintain environmental quality, and promote plant...health.” Doran & Parkin (1994)

- accommodate water entry & facilitate water movement & availability
- resist structural degradation
- sustain productivity & fruit quality

Indicators: pH, EC, CEC, bulk density, aggregate stability, porosity, hydrated pore space, N-P-K etc., organic carbon, microbial biomass, earthworms, food web, others
“Living soil” refers to the “biologically regulated interconnections in the soil ecosystem [that] play key roles in maintaining desirable soil physical and chemical conditions.”

Charles Darwin
1809-1882

- Published 1881
- Based on life-long study
- Habits & effects of earthworms

“Worms prepare the ground in an excellent manner for the growth of fibrous-rooted plants and for seedlings of all kinds...like a gardener who prepares fine soil...In this state it is well fitted to retain moisture and to absorb all soluble substances, as well as for the process of nitrification.” (pp. 309-10)
Justus von Liebig
1803-1873

- German chemist
- Downplayed soil humus
- Ammonia & inorganic minerals more important
- Substituted chemical fertilizers for biologically based soil fertility
Carbon and nitrogen cycles

- **CO₂**: 0.3-0.4%
- **N₂**: 78%

**Processes**:
- **nitrification**
- **denitrification**
- **leaching**
- **AA** (amino acids)
- **protease**

**Organisms**:
- **Rhizobia**
- **Azotobacter**

**Products**:
- **organic matter**
- **humus**
- **tilth**

**Steps**:
- **H₂O** to **CO₂**
- **N₂** to **organic matter**
- **(nitrogen + carbon)**
- **proteins**
Three Studies

Apples

Strawberries

Tomatoes
Washington apple study

- virgin pasture site
- planted 1994, study ended 2003
- Golden Delicious grafted to Gala
- randomized complete block
- managed by the grower
Sustainability of three apple production systems

John P. Reganold*, Jerry D. Glover*, Preston K. Andrews† & Herbert R. Hinman‡

- crop quality
- soil quality
- profitability
- environmental impact
- energy efficiency

Apple Orchard Productivity and Fruit Quality under Organic, Conventional, and Integrated Management

Gregory M. Peck
Department of Horticulture and Landscape Architecture, Washington State University, Pullman, WA 99164-6414

Preston K. Andrews
Department of Horticulture and Landscape Architecture, Washington State University, Pullman, WA 99164-6414

John P. Reganold
Department of Crop and Soil Sciences, Washington State University, Pullman, WA 99164-6420

John K. Fellman
Department of Horticulture and Landscape Architecture, Washington State University, Pullman, WA 99164-6414
<table>
<thead>
<tr>
<th>Year</th>
<th>Conventional</th>
<th>Organic</th>
<th>Integrated</th>
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</thead>
<tbody>
<tr>
<td>1994</td>
<td>Ca-NO₃, Roundup</td>
<td>Poultry compost, Bark mulch</td>
<td>Ca-NO₃, compost, Bark mulch, Roundup</td>
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<td>1995</td>
<td>Ca-NO₃, Roundup</td>
<td>Poultry compost, Woven fabric</td>
<td>Ca-NO₃, compost, Roundup</td>
</tr>
<tr>
<td>1996</td>
<td>Roundup</td>
<td>Woven fabric</td>
<td>Roundup</td>
</tr>
<tr>
<td>1997</td>
<td>Roundup</td>
<td>Cultivator</td>
<td>Roundup</td>
</tr>
<tr>
<td>1998</td>
<td>Roundup, Simazine</td>
<td>Cultivator</td>
<td>Roundup</td>
</tr>
<tr>
<td>1999</td>
<td></td>
<td>Mowed</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Ca-NO₃</td>
<td>Bloodmeal</td>
<td>Ca-NO₃, bloodmeal</td>
</tr>
<tr>
<td>2001</td>
<td>Ca-NO₃</td>
<td>Bloodmeal</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>Roundup, Simazine, Diuron</td>
<td>Ryegrass, vetch, clover</td>
<td>Roundup</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flaming, mowed</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>NH₄-SO₄, Roundup</td>
<td>Clover, bloodmeal, Tilled, mowed</td>
<td>NH₄-SO₄</td>
</tr>
</tbody>
</table>
Soil organic matter
Topsoil

Organic matter (%) vs Year

- CON
- ORG
- INT

* Significant difference
Earthworms
Topsoil

**CON**  **ORG**  **INT**

number/m²

<table>
<thead>
<tr>
<th>Year</th>
<th>CON</th>
<th>ORG</th>
<th>INT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>20</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>1999</td>
<td>10</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2000</td>
<td>10</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2001</td>
<td>100</td>
<td>400</td>
<td>400</td>
</tr>
</tbody>
</table>

* Significant difference
Soil porosity

Topsoil

![Graph showing soil porosity for CON, ORG, and INT treatments in 2002 and 2003. The graph indicates a comparison of porosity levels across different years and treatments.]
Microbial biomass
Topsoil

Carbon

Nitrogen

All higher in ORG

C (mg/kg soil)

N (mg/kg soil)

1998 1999 2000 2001 2002

1998 1999 2000 2001 2002
Soil food web
Topsoil

Glover et al., 2011
Yields

![Yield Graph]

- **CON**
  - 2003: 150
  - 2002: 50
  - 1999: 100
  - 1998: 150
  - 1997: 200
  - 1996: 250
  - 1995: 300

- **ORG**
  - 2003: 120
  - 2002: 40
  - 1999: 80
  - 1998: 120
  - 1997: 160
  - 1996: 200
  - 1995: 250

- **INT**
  - 2003: 180
  - 2002: 60
  - 1999: 120
  - 1998: 180
  - 1997: 240
  - 1996: 280
  - 1995: 320

Hailstorm Topworked
Fruit size

Mean weight (g)

CON  ORG  INT


*  *  *
Fruit size distribution
(1998-99)

Fruit weight (g)

Percent

CON  ORG  INT

<145  145-179  180-203  204-227  228-251  252-81  >281
Fruit firmness
At harvest

**Starch index**

**Golden Delicious**

**Gala**

**Fruit firmness**

**At harvest**

**Starch index**
Fruit firmness
After CA storage

1998-99 Golden Delicious
2002-03 Gala

CON  ORG  INT

*  *  *  *

3-month CA
6-month CA

Force (lbs)
Fruit nitrogen:calcium ratio

Gala

<table>
<thead>
<tr>
<th>Year</th>
<th>CON</th>
<th>ORG</th>
<th>INT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Indicates significant difference.
Soluble solids & acidity

Soluble solids

SSC (°brix)

1998 1999 2002 2003

Golden Delicious Gala

Acidity

Titratable acidity (%)

1998 1999 2002 2003

Golden Delicious Gala
Antioxidant activity

Gala

Skin 5X activity of flesh

TAA (μmol Trolox/200g apple)

<table>
<thead>
<tr>
<th>Year</th>
<th>At harvest</th>
<th>3-month RA</th>
<th>3-month CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference.
Consumer preference
Golden Delicious

More flavor
Sweeter
Tarter

<table>
<thead>
<tr>
<th></th>
<th>Flavor</th>
<th>Sweetness</th>
<th>Tartness</th>
<th>Flavor</th>
<th>Sweetness</th>
<th>Tartness</th>
</tr>
</thead>
<tbody>
<tr>
<td>At harvest</td>
<td>CON</td>
<td>ORG</td>
<td>INT</td>
<td>CON</td>
<td>ORG</td>
<td>INT</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>6-month CA</td>
<td>CON</td>
<td>ORG</td>
<td>INT</td>
<td>CON</td>
<td>ORG</td>
<td>INT</td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

At harvest and 6-month CA, the CON variant scored higher in flavor, sweetness, and tartness compared to ORG and INT variants.
Consumer preference

Gala at harvest

CON  ORG  INT

Firmer  Sweeter  Tarter

2002  2003

*
Consumer preference
Gala after 3-month CA storage

Firmer
Sweeter
Tarter

Firmness  Sweetness  Tartness  Firmness  Sweetness  Tartness

2002  2003

*
California strawberry study

- 13 matched pairs commercial organic & conventional fields
- matched soil, topography, microclimate
- 3 cultivars
- 2004-05
Fruit and Soil Quality of Organic and Conventional Strawberry Agroecosystems

John P. Reganold\textsuperscript{1*}, Preston K. Andrews\textsuperscript{2}, Jennifer R. Reeve\textsuperscript{3}, Lynne Carpenter-Boggs\textsuperscript{4}, Christopher W. Schadt\textsuperscript{5}, J. Richard Alldredge\textsuperscript{6}, Carolyn F. Ross\textsuperscript{7}, Neal M. Davies\textsuperscript{8}, Jizhong Zhou\textsuperscript{9}
# Soil inputs

## 2004-05

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Organic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fumigants</strong></td>
<td>methyl bromide&lt;br&gt;chloropicrin</td>
<td>none</td>
</tr>
<tr>
<td><strong>Fertilizers</strong></td>
<td>compost (4.6-5.5 tons/A)&lt;br&gt; NH₄-SO₄&lt;br&gt;Ca thiosulfate&lt;br&gt;Ca-NH₄-SO₄&lt;br&gt;humic acid&lt;br&gt;kelp extract&lt;br&gt;K-NO₃&lt;br&gt;Na borate&lt;br&gt;urea</td>
<td>compost (8.4-10.2 tons/A)&lt;br&gt;gypsum&lt;br&gt;humic acid&lt;br&gt;kelp extract&lt;br&gt;fish emulsion&lt;br&gt;bloodmeal&lt;br&gt;feathermeal&lt;br&gt;greensand&lt;br&gt;sulfate of potash</td>
</tr>
<tr>
<td><strong>Herbicides</strong></td>
<td>Paraquat, Devrinol</td>
<td>none</td>
</tr>
</tbody>
</table>
# Soil biological properties

## 2004-05

<table>
<thead>
<tr>
<th>Biological property</th>
<th>Conventional</th>
<th>Organic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total C (g C/kg soil)</td>
<td>8.25</td>
<td>10.04 *</td>
</tr>
<tr>
<td>Total N (g N/kg soil)</td>
<td>0.666</td>
<td>0.867 **</td>
</tr>
<tr>
<td>Organic matter (mg/kg soil)</td>
<td>1.46</td>
<td>1.84 *</td>
</tr>
<tr>
<td>Microbial biomass (µg CO₂-C/g soil)</td>
<td>96</td>
<td>249 ***</td>
</tr>
<tr>
<td>Readily mineralizable C (µg CO₂/g)</td>
<td>14.1</td>
<td>17.7 **</td>
</tr>
<tr>
<td>Basal respiration (µg CO₂/g)</td>
<td>0.35</td>
<td>0.47 *</td>
</tr>
<tr>
<td>Mycorrhizae (per mm root length)</td>
<td>104</td>
<td>122</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001
Soil carbon & nitrate

CON  ORG

Percent of total C or N

Microbial C  Nitrate

*
Soil gene activity

**Fungi**

- CON
- ORG

**Prokaryotes**

- CON
- ORG

Signal intensity (10^3)
Soil gene activity

All significantly higher in ORG
Amino acid turnover

Fruit size & dry matter

**Graph 1:**
- **Y-axis:** Weight (g)
- **X-axis:** CON and ORG
- **Legend:**
  - CON: Red bar
  - ORG: Green bar
- **Note:** * indicates a significant difference

**Graph 2:**
- **Y-axis:** Dry matter (%)
- **X-axis:** CON and ORG
- **Legend:**
  - CON: Red bar
  - ORG: Green bar
- **Note:** * indicates a significant difference
Soluble solids & titratable acidity

Diamante

°brix or mg citric acid/g FW

SSC

TA
Phytonutrients

Vitamin C

AsA (mg/g FW)

Phenolics

Phenolics (mg GA/g FW)

Antioxidants

Trolox equivalents (mmol/g FW)

* indicates statistical significance.
Fruit weight loss

Percent (2 days at 20C)

CON ORG

*
Fungal rot

Survival distribution function

Time (days)

Wilcoxon P > X² < 0.0001

Grey mold
Consumer preference

Acceptance

Tartness

Flavor

Juiciness

Sweetness

Appearance

All varieties

Diamante

Diamante

Diamante

Diamante
Consumer preference

Driscoll tasters

WSU tasters

Overall
Texture
Flavor
Overall
Flavor
Juiciness
Sweetness
Tartness
Appearance

Preference (%)
Nitrogen uptake by strawberries

Tomato mulch studies
USDA Beltsville

Yield

Black plastic
Hairy vetch

Yield (kg/plant)

Black plastic
Hairy vetch


Hairy vetch (Vicia villosa)

Black plastic

Yield
Gene expression in tomato leaves

All significantly higher in vetch mulch

Senescence genes in tomato leaves

Cytokinin-responsive → delays senescence

Black plastic

Hairy vetch

ACC synthase → hastens senescence

Black plastic

Hairy vetch

Days after transplanting

80  96  108

ACC: 1-aminocyclopropane-1-carboxylate
Reduced senescence & disease

Leaf senescence

Days after transplanting

Foliar diseases

Days after transplanting

- Black plastic
- Hairy vetch

Early blight
Septoria leaf spot
Amino acids in tomato fruit

Ripe fruit

Relative abundance (NMR)

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Black plastic</th>
<th>Hairy vetch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alanine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspartic acid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asparagine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glutamine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isoleucine</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threonine</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Valine</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>GABA*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td></td>
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</tr>
</tbody>
</table>

Non-essential Essential

GABA: Gamma amino butyric acid

Characteristics of “living soil”

• Inputs of organic amendments & fertilizers (compost, plant litter, etc)
• High microbial populations, biological diversity & metabolic activity
• High total carbon & nitrogen, but equal or lower readily available nitrogen
Carbon and nitrogen cycles

- CO₂ 0.3-0.4%
- N₂ 78%
- Rhizobia
- Azotobacter
- organic matter (nitrogen + carbon)
- humus
- leaching
- nitrification
- denitrification
- mycorrhizae
- AA protease
- proteins
Conclusions

• Although specific mechanisms and soil-plant interactions are ill-defined, there appears to be a link between soil health and fruit quality.

• Based on research that aims to build soil organic matter, fruit quality appears to be improved.

• Is it enough improvement to warrant the investment?

• Perhaps as inorganic fertilizer costs increase, regional efforts to produce compost and other sources of organic nutrients will gain favor.
Supporting organizations

- USDA United States Department of Agriculture
- Cooperative State Research, Education, and Extension Service
- Washington Tree Fruit Research Commission
- Organic Farming Research Foundation
- Center for Sustaining Agriculture & Natural Resources
- Driscoll’s: The Finest Berries in the World
- Pacific Gold
- Stemilt: World Famous Fruit
Questions?

“Where no kind of manure is to be had, I think the cultivation of lupines will be found the readiest and best substitute.”
_Columella, 1st century Rome_

“Organic matter functions mainly as it is decayed and destroyed. Its value lies in its dynamic nature.”
_W.A. Albrecht, 1938_

“Grass is a source of strength of agriculture and, therefore, to the nation.”
_Henry Wallace, 1940_