Soil: The Super Ecosystem of Ecosystems
Soil Balance

DI\_V\_E\_R\_S\_I\_T

D\_I\_V\_E\_R\_S\_I\_T

CHEMICAL

PHYSICAL

BIOLOGICAL
Principles of Soil Management

- Air Management \rightarrow Aerify

  - Water Management
  
  - Decay Management

  » Nutrient Management

"What are your yield limiting factors?" Don Schriefer
Key-Line Sub-Soiler
Clifton Park System  
Robert Elliot, April 25, 1895  
Breaking up hard pans & increasing yields on alluvial flat bottomland soils  
Sowed April 25, 1895  
Cut for hay 1896 (spring)

- 5 # cocksfoot
- 5# meadow foxtail
- 5# tall fescue
- 7# meadow fescue
- 4# timothy
- 1# wood meadow grass
- 1# rough stalked meadow grass
- 2# white clover

- 2# alsike clover
- 2# perennial red clover
- 2# kidney vetch
- 2# Lucerne
- 3# chicory
- 8# burnet
- 1# sheep’s parsley
- ½# yarrow

1896 (spring) Hay yield = 2 1/2 tons dry matter/acre plus heavy lamb grazing
Sept 11, 1896

Hardpan Investigation

- Hardpan 14” deep
- Hardpan thickness 10-12” thick
  - 30”: chicory roots
  - 20”: burnet and vetch roots
  - 8-10”: Lucerne roots

14” + 12” = 26”
Depth to subsoil
Example of Rye Grass (Winter Cereal)

Single Rye Plant: 9 Roots
18,000 Root Hairs
24 Meters Length
12 m³

Single Rye Plant/Season: 6,000 miles of roots that grow out, recede, grow out, recede (pulsing)
Example of Kentucky Bluegrass (perennial)

Single K.B. Plant
122 Roots
61,000 Root Hairs
74 Meters Length
26 m³
Roots of Switch Grass
Roots of Compass Plant
Wheat Grass vs. Wheat
Estimated numbers of common micro-organisms found in *healthy* agricultural soils:

<table>
<thead>
<tr>
<th>Organism</th>
<th>Per 1 gram</th>
<th>Avg. lbs/acre/foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>3,000,000 - 500,000,000</td>
<td>500-1000</td>
</tr>
<tr>
<td>Actinomycetes</td>
<td>1,000,000 - 20,000,000</td>
<td>800-1500</td>
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<tr>
<td>Fungi</td>
<td>5,000 - 1,000,000</td>
<td>1500-2000</td>
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<tr>
<td>Protozoa</td>
<td>1,000 - 500,000</td>
<td>200-400</td>
</tr>
<tr>
<td>Algae</td>
<td>1,000 - 500,000</td>
<td>200-300</td>
</tr>
<tr>
<td>Yeasts</td>
<td>1,000 - 100,000</td>
<td></td>
</tr>
<tr>
<td>Nematodes</td>
<td>10 - 5,000</td>
<td>25-30</td>
</tr>
</tbody>
</table>
Bacteria Estimates: 2-3 million species
Fungi Estimates: 1.5 Million species

Only 2-5% have been described/named
Vertebrates (1)

Snails and Slugs (100)

Potworms and Earthworms (3,000)

Insects, Myriapods, Spiders, Diplurans (5,000)

Rotifers and Tardigrades (10,000)

Springtails (50,000)

Mites (100,000)

Nematodes (5,000,000)

Protozoa (10,000,000,000)

Bacteria and Actinomycetes (10,000,000,000,000)
The Carbon to Nitrogen Cycle

The Soil Food Web

- Shoots
- Roots
- Algae
- P-Bacteria
- Lichen
- Organic Matter
- Dead Material (from all boxes)

- Plant-feeding Nematodes
- Fungal-feeding Mites
- Predatory Nematodes
- Predatory Mites
- Higher level Predators

- Mycorrhizal Fungi
- Fungal-feeding Nematodes
- Bacterial-feeding Nematodes
- Flagellates
- Amoebae
- Ciliates

- N.P. nutrients to plant
- c to fungus
- Complex, recalcitrant carbons

- Simple sugars

C:N = 5:1  C:N = 10:1  C:N = 30:1
Lumbricus terrestis

- 2000 worms = 125 lbs castings per year
- 25 worms/cu ft = 1,000,000 worms/acre = 62,500 lbs castings/year
- 15 worms/cu ft = 645,000 worms/acre = 41,400 lbs castings/acre
- Earthworms eat 1/3 body weight in soil daily
- Healthy population moves 20 tons soil/acre/year
- Burrow up to 8 feet deep (Air! Roots!)
- Up to (6) year life span
- New Zealand Pastures = transplanted European worms
  - 8,000,000 worms/acre
  - 10 X 10 meter grids @ 25 worms = 75% more grass in 3 years
Pore & Surface Area in Sand, Silt & Clay
- GRANULAR -

Figure 11.8
Fine: < 2 mm.

Figure 11.9
Medium: 2 to 5 mm.

Figure 11.10
Coarse: 5 to 10 mm.

- BLOCK -

Figure 11.11
Very fine: < 5 mm.

Figure 11.12
Fine: 5 to 10 mm.

Figure 11.13
Medium: 10 to 20 mm.

- PLATE -

Figure 11.14
Thin: < 2 mm.

Figure 11.15
Medium: 2 to 5 mm.

Figure 11.16
Thick: 5 to 10 mm.
The Koch Snowflake
Colloids are Fractals

- Enormous Surface to Mass Ratio
- “Burning” Fine Steel Wool vs. a Nail
How “BIG” is Your Soil??

Clay Ranges: 10m²/gm - 800 m²/gm

Potential Surface Area of 45% Clay Soil at 1 ha X 1.5m depth (football field)

8,700,000 km²
5,750,000 m²
Clays Store Energy & Information!

- Silicon Based (wild, undomesticated semi-conductors)
- Can Assemble into Varied Shapes
- Domains of Disorder from Isomorphic Substitutions
- Reactions are Catalyzed (very small amounts can accelerate chemical processes by $10,000 \times (+)$!)
- Clay Moistened with Water, Solvents, Irradiated, Fractured, will emanate UV and other light wavelengths up to years

Wilford, J. 1985 New finding backs idea that life started in clay rather than seas New York Times
<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Soil content</th>
<th>Annual Plant Uptake</th>
<th>Years of supply in a 4-inch soil layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% by weight</td>
<td>lb/acre</td>
<td>years</td>
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<tr>
<td>Calcium</td>
<td>1</td>
<td>45</td>
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<tr>
<td>Potassium</td>
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<td>27</td>
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<tr>
<td>Nitrogen</td>
<td>0.1</td>
<td>27</td>
<td>50</td>
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<tr>
<td>Phosphorus</td>
<td>0.08</td>
<td>6</td>
<td>150</td>
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<tr>
<td>Magnesium</td>
<td>0.6</td>
<td>3.6</td>
<td>2,000</td>
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<tr>
<td>Sulfur</td>
<td>0.05</td>
<td>1.8</td>
<td>320</td>
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<tr>
<td>Iron</td>
<td>4.0</td>
<td>0.5</td>
<td>100,000</td>
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<tr>
<td>Manganese</td>
<td>0.08</td>
<td>0.4</td>
<td>3,000</td>
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<td>Zinc</td>
<td>0.005</td>
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<td>2,000</td>
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<tr>
<td>Copper</td>
<td>0.002</td>
<td>0.1</td>
<td>1,000</td>
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<tr>
<td>Chlorine</td>
<td>0.01</td>
<td>0.05</td>
<td>200</td>
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<tr>
<td>Boron</td>
<td>0.001</td>
<td>0.03</td>
<td>400</td>
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<tr>
<td>Molybdenum</td>
<td>0.0003</td>
<td>0.003</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Table 2-3

Microbial Bio-Mass

• Make up 50% of Earth’s Total Biomass
• More Microbial Cells on Earth than Stars in Universe
• 80% of All Biodiversity is Microbial
• More Microbial Cells in and on Humans (and Animals) than Cells Comprising Them
Up to 60% of Photosynthetic Carbon is sent to the roots

- Antioxidants
- Simple & Complex Acids
- Complex Carbohydrates
- Proteins
- Essential Oils
- Chelating Agents
- Microbial Stimulants
- Secondary Metabolites
Root Tip Exudates
Healthy vs. Unhealthy Villi
The Rhizosphere: “The Nectar of Roots”

- Sugars (fructose, glucose, ribose, etc)
- Up to 27 amino acids
- Nucleotides, flavones, phenolics
- Lipids, mucilage, gums, resins
- Water soluble/ 3-5X non-water soluble/ 8-10X volatile
- Hundreds of compounds; Thousands of combinations
Rhizosphere

- 1-5% of Soil Volume
- 1-5mm from Root Surface
- Microbial Population 10-100X Higher than Other soil
- Microbes Only Occupy 7-15% of Actual Root Surface
- Up to 25% (+) Plants Photosynthetic Energy
Mucilage (Mucigel)

- Protects root apical zones
- Lubricates roots moving through soil
- Increases uptake of ions
- Improves soil-root contact (especially dry soils)
- Aggregates soil in rhizosphere
- Dry soils produce more mucilage
- More uptake of trace minerals
- Binds with heavy metals (Cd, Pb, Cu)
- Exchanges with calcium
Mucigel Menu

- **Amino Acids**
  - Asparagine
  - Methionine
  - Adenine
  - Serine
  - Aspartate
  - Valine
  - Glutamate
  - Leucine
  - Lysine
  - Tryptophan
  - Tyrosine
  - Glutamine
  - Phenylalanine
  - Histidine
  - Arginine
  - Alanine
  - Glycine
  - proline

- **Vitamins**
- **Sugars**
- **Tannins**
- **Alkaloids**
- **Phosphatides**
- **Indole**
- **Salicylic Acid**
- **Purines**
- **Pyrimidines**
- **Nucleic Acids**
- **Tartaric Acid**
- **Oxalic Acid**
- **Malic Acid**
- **Citric Acid**
- **Scopoletin**

Pinocytoses: Uptake of Complex Molecules Through Root Cell Membranes (e.g. Amino Acids, Amino Sugars, Nucleic Acids, etc)
Organic Compounds in Organic Matter

- Fats, Oils, Waxes
- Carbohydrates (Sugars, Starches, Cellulose)
- Lignins
- Tannins (Simple and Condensed)
- Pigments and Derivatives, including Chlorophyll, Cyanidins, etc.
- Polysaccharides, as Gels, Slimes Secreted by Fungi, Bacteria (up to 40% of OM)
- Minerals
- Organic Acids, Aromatic Compounds, Alcohols, Hydrocarbons, etc.

90% of Plant Species Use Mycorrhizae

NATURE USES
FRactal
GEOmetry
CRUMB STRUCTURE REQUIRES BIOLOGY
Glomalin Properties

1. Doesn’t Dissolve in Water
2. Resistant to Decay (“PVC”) 10-50 years
3. Glue Soil Aggregates
4. Insulates VAM Hyphae from Nutrient Loss
5. Average 27% of Organic Soil Carbon
6. 100’s of Meters of Hyphe per tsp. of soil equals large amounts glomalin
7. 25% more Weight than Humic Acid
Albert Schatz, PhD

- Discovered Streptomycin
- “Chelation as a Biological Weathering Factor in Pedogenesis” 1954
- The Importance of Metal-Binding Phenomena in the Chemistry and Microbiology of the Soil” (Advancing Frontiers of Plant Science 1963)

Feb. 2, 1922 - Jan. 17, 2005
“Lost City of the Incas”
by Hiram Bingham (US Senator)

Machu Picchu
&
Cuzco
Cuzco Fortress

- Small Blocks: 10-20 Tons
- Large Blocks: 200-300 Tons
The Pito Bird

- Softens Rock into “Clay”
- Harakkeh' ama plant contains chelating chemicals
Lichen: Chelation Therapy For Soil

- 36% of Dry weight = Chelators
- Thalli: Non-differentiated Combo of Algae (Sugars) & Fungi (Minerals)
  - Biblical Manna?
  - Japanese & Chinese “Manna”
Humic Acids: Chelating Agents in Organic Soils

- Amphoteric anions & cations are chelated
- British Soil Scientist: Siegfried Marion, “Biogenic Carbon” or energy from “Living Carbon”
- German Scientist: Fritz Albert Popp, “Biophotons” emitted from living cells
- French Scientist: Gaston Naessens, “Somatids” or basic energy units that are precursors to life
- German Scientist Wilhelm Reich, “Bions”, non-living elements, pre-cursors to life
Humic Acids are Buffers

- Excessive Sodium
- Excessive Magnesium
- Excessive Bicarbonates
- Pesticides/Metal Residues
Humic Acids Stabilize (Complex) Leachable Anions

• Boron
• Selenium
• Sulfur
• Chromium
• Nitrate
• Iodine
• Molybdenum
Humic Acids Increase Plant Cell Membrane Permeability by up to 35%
Soil Carbon = Crop “Irrigation”!

- Soil Bulk Density @ 1.4 gms/cubic cm
- For EVERY 1% Increase in OM:
  → Additional 4.5 gallons of water stored per top 12” soil per square yard;
  → Equal to: Additional 18,000 gallons per Acre
Loss of Humus = Drought!

3% Loss of OM = Loss of 54,000 gallons per acre
Richland County, Ohio 1940

Highly Diversified Farm Supporting Five Families (40 People) on 1000 Acres Consisting of Five Farms
Weekends At Malabar Farm 200-1000 Visitors/Week
One of 15 Productive Malabar Springs
Soil Conservation Creates Adequate Water
MAKING SOIL ON CEMETERY FIELD

• Initially, Topsoil Was Gone- Only Subsoil

• Eight Years Later:
  – 4 Inches of Topsoil
  – Ladino Roots- 8 Inches Deep
  – Brome Grass Roots- 24 Inches Deep
  – Alfalfa Roots- 12-14 Feet Deep
FORMULA FOR SOIL BUILDING

• Adequate Liming & Light Fertilizing
• Grazing to Produce Manure
  – Hormones
  – Microbes
  – Enzymes
  – Carbon
• Plow Down of Cover Crops (Legumes)
• Tight Rotations, with Small Grains
• Mowing For Mulch
  – Hay/Weeds Allowed to Grow; Mowed 2X/Summer
  – Will Help Raise Yields on Poor Fields 500% Within (1) Year
  – Chokes Out Weeds
INSTITUTING ALFALFA ON WORN OUT LAND

- 4 Tons/Acre Limestone (Every 12 years)
- 300 Lbs/Acre of 5-12-12 (Every 3 Years)
- Seeded Directly Without Plowing on Trash Mulched Surface
  - Seed Mixture: Alfalfa 9 lbs, Brome 5 lbs, Ladino 1 lb per Acre
- Year (1) and (2) Show Potash & Boron Deficiencies
- Year (3) and Beyond, Glacial Subsoil Remedies Deficiencies
- Year (3) and Beyond, Significant Decline in Leaf Hopper
INSTITUTING ALFALFA ON WORN OUT LAND

• Mature Alfalfa Growing on Glacial Drift Soil = No Leaf Hoppers!

• Mature Alfalfa Growing on Clay Subsoil Field = Heavy Leaf Hopper Damage

• Winter of 1945-46: Large Heaving Loss on Clay Field  
  NO Heaving Loss on Glacial Drift Soil

• Alfalfa & Sweet Clover Considered a Very Difficult Crop in Knox Co. Ohio (Clue: Observe Hedgerows & Roadsides!)
Seaman Tiller
Graham Chisel Plow
Sheet Composting with Seaman Tiller & Chisel Plow
No Till Corn
Corn in a Drought Year @ 25,000 Plants/Acre
Phytochemistry of Plant Constituents

- Amino Acids
- Carbohydrates
- Lipids
- Polyphenols
- Terpenes
- Sterols
- Alkaloids

Over 80,000 Isolated Plant Compounds
Plant Secondary Metabolites as Defense

- Grazing Animals (tannins, essential oils, alkaloids)
- Ultra Violet Radiation
- Bacteria, Fungi, Virus
- Defense Against Competing Plants (walnuts)
- Vulnerable Fruits & Younger Tissue are higher in PSM’s
Plant Secondary Metabolites as Attractants

Color to Attract Pollinators

Perfume to Attract Pollinators

Molecular Signals to Promote Colonization by Mycorrhiza and Rhizobia
Pollinators

• Hundreds of Thousands!
  – Bats, mosquitoes, mice, ants, opossums, bees, monkeys, beetles, flies, lizards, birds, butterflies, flying foxes
  – <6% are identified
  – Species of Pollinators
    • 1,500 Birds
    • 15,000 Wasps
    • 40,000 Bees
    • 20,000 Butterflies
    • 14,000 Flies
    • 200,000 Beetles
    • 165 Bats
    • 300 miscellaneous mammals
Plant Secondary Metabolites & Their Relationship to Nutrition

• Mn, Cu, Fe, B, Co are enzyme cofactors
• Nitrate inhibits phenol metabolism, hastens wilt
• NH₄ increases Mn uptake → phenol production
• K deficiency → decreases fungistatic phenols to rice bacterial blight, Botrytis cenera (grapes), mildew/rusts (wheat)
• K → increase arginine → fungestatic phenols against phytophthora (potatoes)
• K → decrease glutamine, glutamic acid in tobacco (Alternaria, Cercospora, Sclerotinia resistance)
• Mn → Glycoproteins (lectins) → resistance to ceratocystis fimbriota (blackrot) in sweet potato and phytophthora infestans (late blight) in potato
• Mn → inhibits aminopeptidase activity, cause of rusty mildews
Systemic Activated Resistance (SAR)

- Directly Involved with Response to Stress of Pests
- Synthesis is immediate - can be detected within (1) hour
- Peaks @ 48-72 hours
Systemic Activated Resistance (SAR)

• Feedback Systems of Communication
  – Signal initiated by pathogen trigger (signature protein)
  – Initiates signaling molecule (e.g. systemin)
  – Cascade of gene expression
  – Systemin initiates Jasmonic Acid (J.A.)
    • J.A. production very similar to prostaglandin production
    • J.A. is modulated by Salicylic Acid (S.A.)
    • Low dose S.A. enhances plant growth (e.g. 10 ppm increases nitrate reductase enzyme)
    • High dose inhibits growth and J.A. production
    • J.A. stimulates Phytoalexin production (stilbene, resveratrol)
Terpenes

- Monoterpenes
  - Anti-microbial
  - Anti-cancer
    - Essential Oils
      - Peppermint
      - Thyme
      - Oregano
      - Citrus
    - Small Volatile Molecules
# Antibiotic Properties of Essential Oils

**Plant Essential Oils Tested for Antibacterial Properties**

<table>
<thead>
<tr>
<th>Almond (bitter)</th>
<th>Caraway</th>
<th>Fennel</th>
<th>Melissa</th>
<th>Rosemary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almond (sweet)</td>
<td>Cardamom</td>
<td>Geranium</td>
<td>Mint (apple)</td>
<td>Sage</td>
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<tr>
<td>Angelica</td>
<td>Celery</td>
<td>Ginger</td>
<td>Nutmeg</td>
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<td>Anise</td>
<td>Cinnamon</td>
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<td>Basil</td>
<td>Citronella</td>
<td>Lavender</td>
<td>Orange (bitter)</td>
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<tr>
<td>Bay</td>
<td>Clove</td>
<td>Lemon</td>
<td>Parsley</td>
<td>Star Anise</td>
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<tr>
<td>Bergamot</td>
<td>Coriander</td>
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<td>Calamus</td>
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<td>Eucalyptus</td>
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<td>Test Bacteria</td>
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<tr>
<td>Acinetobacter calcoacetica</td>
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<td>Alcaligenes faecalis</td>
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<td>Bacillus subtilis</td>
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<td>Lactobacillus plantarum</td>
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<td>Leuconostoc cremoris</td>
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<td>Moraxella sp</td>
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<td>Proteus vulgaris</td>
<td>Pseudomonas aeruginosa</td>
<td>Salmonella pullorum</td>
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<td>Serratia marcescens</td>
<td>Staphylococcus aureus</td>
<td>Streptococcus faecalis</td>
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<tr>
<td>Yersinia entercolitica</td>
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Test Results

- All 50 Plant E.O.’s inhibited at least (1) bacterium
- 41 plant E.O.’s inhibited (5) or more bacterium
- 33 plant E.O.’s inhibited (10) or more bacterium
- 10 plant E.O.’s inhibited (20) or more bacterium
<table>
<thead>
<tr>
<th>Essential Oil</th>
<th>Number of genera</th>
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<tr>
<td>Angelica</td>
<td>25</td>
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<tr>
<td>Bay</td>
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<td>Cinnamon</td>
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<td>Clove</td>
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<tr>
<td>Thyme</td>
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<tr>
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<td>Marjoram</td>
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<tr>
<td>Pimento</td>
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<tr>
<td>Geranium</td>
<td>21</td>
</tr>
<tr>
<td>Lovage</td>
<td>20</td>
</tr>
</tbody>
</table>
Odor Blends of Attacked Plants

- Composed of more than 200 separate compounds
  - Directly affect herbivores behavior
  - Attract enemies of attacking herbivores (e.g. predatory mites, parasitical wasps)
  - Release of stored plant compound (post inhibitins)
  - De Novo BioSynthesis of new volatile compounds (phyto-alexins)
- Predators can distinguish infestations by its host herbivores from non-host herbivores
Priming with Exogenous Volatiles (PSM’s)

- Clipped sagebrush released volatiles
  - Reduced herbivore damage of tobacco plants
  - Increased mortality of young Manduca sexta caterpillars
- Incomplete turning-on of defense related processes
- Reducing biochemical investment in defenses until actual attack


Insect Trials on Greenhouse Lebanese Cucumbers

- Striped Cucumber Beetle
- Two Spotted Spider Mite
- 1% Dilution vs. Control

Dates of Application
- August 16, 2010
- August 25, 2010
- September 3, 2010
- September 13, 2010

Result: 100% Control for Both Pests
Systemic Effect for 9-10 Days
Downy Mildew Trials on Greenhouse Lebanese Cucumber

- 1% Dilution of Phyto-Guard™ Terpenoids & 1% Extend vs. Control

Dates of Application
September 6, 2010 (15% Infestation)
September 13, 2010
September 20, 2010
Treated Scale (Neolecanium comumbarvum)
Botrytis on Peony

• Botrytis commencement on July 10, 2010
  Dilution at 0.5% Phyto-Guard™ plus 1%
  “Extend”

  Date of Application
  July 14, 2010
  August 12, 2010
  August 30, 2010
Rapid Changes in Tree Leaf Chemistry Induced by Damage: Evidence for Communication Between Plants

“For in the end we will conserve only what we love. We will love only what we understand and we will understand only what we are taught.”

Baba Dioum

African Conservationist