Soil Chemistry

It’s more complicated than we know

Roy Farrow
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Soil Chemistry

It’s more complicated than we know

But you can leave most of it to the chemists
Issues

1. Conflict between the Agrochemical Industry and Organic Gardening Principles

2. Soil Science and Dynamics

3. Soil Testing and Soil Reports
Horticulture = growing plants for Research, Conservation and Enjoyment

Agriculture = growing plants for food

Silviculture = growing trees for wood products

Floriculture = growing perennials and annuals for cut flowers
Cropping

Soil Reservoir
Justus Von Liebig  
1803-1873  
Father of Agrochemical Science

Law of the Minimum

Plant growth is limited by the least abundant nutrient
Haber – Bosch Process

~1913

Production of nitrogen fertilizer in relation to world population

Nitrogen + Hydrogen $\rightleftharpoons$ Ammonia

$N_2 + 3H_2 \rightarrow 2NH_3$
“The slow poisoning of the life of the soil by artificial manure is one of the greatest calamities which has befallen agriculture and mankind.”

Sir Albert Howard
1873-1947
Father of Organic Gardening

“The essence of humus manufacture is first to provide the organisms with the correct raw material and then to ensure that they have suitable working conditions.”
Sir Albert Howard’s Law of Return

Recycle all plant and animal wastes to the soil
“Current levels of agricultural production depend on cheap oil, but this dependence needs to decline to avoid food shortages and higher prices in the future.”

“Integrating crop rotation, livestock production and zero-tillage in the Brazilian Cerrado resulted in sustainable grain and meat production on the same lands using less fertilizer and herbicides and without requiring further deforestation (in addition to less soil erosion, improved soil biological activity and nutrient recycling and lower greenhouse gas emissions)”

https://na.unep.net/geas/getUNEPPageWithArticleIDScript.php?article_id=81
Let’s talk about plants and soil
# Elements Required by Plants

<table>
<thead>
<tr>
<th>Base Elements</th>
<th>Macronutrients</th>
<th>Micronutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen (O)</td>
<td>Nitrogen (N)</td>
<td>Boron (B)</td>
</tr>
<tr>
<td>Hydrogen (H)</td>
<td>Phosphorus (P)</td>
<td>Chlorine (Cl)</td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>Potassium (K)</td>
<td>Cobalt (Co)</td>
</tr>
</tbody>
</table>

Plants get base elements from the air. All other nutrients come from the soil.
# Elements of Plants

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage by weight</th>
<th>Relative number of atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>1.5</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Potassium</td>
<td>1.0</td>
<td>250,000</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.5</td>
<td>125,000</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.2</td>
<td>80,000</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.2</td>
<td>60,000</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.1</td>
<td>30,000</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.01</td>
<td>3,000</td>
</tr>
<tr>
<td>Boron</td>
<td>0.0067</td>
<td>2,000</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0067</td>
<td>2,000</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.003</td>
<td>1,000</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.001</td>
<td>300</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0003</td>
<td>100</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.000003</td>
<td>1</td>
</tr>
<tr>
<td>Cobalt</td>
<td>&lt;0.000000</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

[www.waternut.org](http://www.waternut.org)
Nitrogen is essential in proteins, nucleotides and chlorophyll

Phosphorous forms the backbone of DNA and is the main component of ATP

Most enzymes have a single heavy metal atom (Mn, Mo, Co) at their center which serves as an electron bank for reactions
All of these elements exist simultaneously in multiple forms within the environment and are constantly cycling between those forms.
Interupted

We separate...

We alter...

We compact...

We remove...

Cyclus Interruptus
Speaking of soils...

$\text{KAISi}_3\text{O}_8-\text{NaAlSi}_3\text{O}_8-\text{CaAl}_2\text{Si}_2\text{O}_8$
The soil particle is like a bus. The seats are the negative charges. All the seats must always be full with positively charged particles. Hydrogen \((H^+)\) has a weak charge and Ammonium \((NH_4^+)\) a stronger charge, so they “exchange” seats if the Ammonium ion wants to sit down.

Cation Exchange Capacity (CEC, meq/100 g)

The Cation Exchange Capacity is a measure of how many negatively charged sites are available in a particular soil.
Plants make cations available by flooding the rhizosphere with $H^+$ ions simply by respiring $CO_2$ into the soil solution.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 \rightarrow H^+ + H^+ + CO_3^{2-}$$
Cation Exchange Capacity by soil type

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>CEC (meq/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Less than 5</td>
</tr>
<tr>
<td>Silt</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Clay</td>
<td>10 - 50 ish</td>
</tr>
<tr>
<td>Compost/humus</td>
<td>up to 400</td>
</tr>
</tbody>
</table>

CEC is all about surface area

- Fine sand 0.24mm²
- Silt 2.4mm²
- Clay 24mm²
Saturation

Field Capacity

Permanent Wilting Point

Three States of Soil Solution
Four States of Nutrients

1. Parent minerals (CaCO$_3$, CaSO$_4$, Mica, Granite, etc.) [rocks]
2. Parent organics (sugars, proteins, lignins, etc.) [dead stuff]
3. Dissolved ions in solution
4. Exchangeable ions adsorbed onto particle surfaces
Cations

Anions

Leached Out of Root Zone

Absorbed By Plants

Yay!

Nutrients Enter Into the Root Zone

Weathering + Decomposition (fertilizer)

Adsorbed Onto Soil Particles

Soil Solution

Boooo!

Absorbed By Plants

Yay!
Soil Life

Cations $^+$

Anions $^-$

Soil Humus

Adsorbed Onto Soil Particles

Soil Solution

Nutrients Enter Into the Root Zone

Weathering + Decomposition

Leached Out of Root Zone

Absorbed By Plants

Yay!

Boooo!
The Fuel that powers this engine
Compounds of Plant Residues (Humus)
Metabolic Carbon
High N:C
Proteins, Sugars

Structural Carbon
Low N:C
Cellulose, Lignins
What Happens to Organic Soil Amendments?

**Sugars, Proteins** (Low Lignin, high N)
Decomposes quickly (months)
- Soil structural stability, food for microorganisms and mineralization of nutrients

**Cell walls** (High lignin, low N)
Decomposes slowly (years)
- Food for some microorganisms, mineralization of some nutrients

**Depositors**
- Turnover 1-2 years

**Slow Fraction**
- Turnover 15-100 years

**Passive Fraction**
- Turnover 500-5000 years

- Cation exchange capacity, water holding capacity
Functions of Root Exudates

1. Regulation of soil microbial community
2. Encourage beneficial symbiosis
3. Change physical and chemical properties of soil
4. Inhibit growth of competing plants

5%-21% (40%) of all photosynthetically fixed carbon is transferred to the rhizosphere through exudates
Bioremediation of Petroleum Polluted Soils
Jumping to Soil Reports!
How to Take a Sample

Aerial sampling when soils are saturated (after heavy rain) is not recommended until all surface water has drained. You will need:

- A shovel, trowel, or other soil probe
- A clean plastic container, such as a bucket
- Sampling bags (Ziploc style bags will work)
- Designate sample areas by what is growing there. For example, if you have a garden of mixed vegetables, that could be one sample area. If you have a pasture and a garden, take separate samples of each. If there has been some terracing, such as contouring, soil moisture, and type (clay, loam, sand, etc.) at each corner point. Designate separate sample areas for each characteristic.

1. For each sample, take 10 to 15 sub-samples across the whole sample area. Be sure to get even coverage of the entire area. Take randomly placed but evenly distributed sub-samples. A zigzag pattern works well for larger sample areas. Make thin slices of soil with a shovel or trowel for a sampling depth between three and ten inches of soil, depending on the crop and time of year. (See the table below for instructions.) Place the sub-samples in a clean container.

2. Thoroughly mix the 15 sub-samples and scoop out TWO to THREE CUPS of the soil and place into a bag.

3. Label the bag with your:
   - Name
   - Five letters and/or numbers that will help you remember where the sample came from (such as PST, 12345)

4. For each sample, repeat steps 2-3 for each area.

5. Mail or deliver the samples immediately. Soil samples must continue to change even after sample collection, due to exothermic activity. It is critical, therefore, that this activity be stopped as soon as possible after sampling (within 24 hours).

6. If you are not mailing the samples that day, put the sealed samples in a refrigerator. If samples are over saturated, put soil on a newspaper and air dry overnight in a cool location. The soil should have moisture similar to damp sponge.

7. Fill out the Soil Sample Information Sheet and mail or deliver samples to:
   King Conservation District
   Attn: Soil Sampling
   1107 SW Grady Way, Suite 130
   Renton, WA 98057

Results are generally available within three weeks and will be emailed to you, or sent via postal mail.

### Guidelines for Sampling Depth

<table>
<thead>
<tr>
<th>Type of Crop</th>
<th>Sampling Depths</th>
</tr>
</thead>
<tbody>
<tr>
<td>All samples</td>
<td>1&quot;</td>
</tr>
<tr>
<td>Established lawns &amp; pasture</td>
<td>4&quot;</td>
</tr>
<tr>
<td>New lawns &amp; pastures</td>
<td>6&quot;</td>
</tr>
<tr>
<td>Gardens</td>
<td>6&quot;</td>
</tr>
<tr>
<td>Trees &amp; shrubs</td>
<td>6&quot;</td>
</tr>
<tr>
<td>Commercial crops</td>
<td>6&quot;</td>
</tr>
</tbody>
</table>

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http://kingcd.org/programs/better-soils/healthy-soil/
Sampling Guidelines

One of the keys to getting accurate test results is proper sampling. Soil composition can vary from one spot to another in areas that look uniform. This may be due to uneven application of fertilizer in previous years, or simply due to natural variations. Make sure that your samples are representative of your yard, garden or field. To do this, take at least 5 samples from the area to be tested and mix them to form a composite. If your garden or field has areas with different soil texture, color or fertilization history, they should be sampled separately.

1. Scrape off surface residue/litter.
2. Sample from the soil surface to the depth of tillage - usually 6-8 inches for cultivated crops and 3 inches for turf.
3. Take a minimum of 5 samples and combine them in a clean container. One common sampling method is to sample in a "W" pattern, with a sample at each point. Mix the soil thoroughly.
4. Place about 1 cup in a plastic bag (such as a zip-top sandwich bag) or other container. Mark the bag with a sample.

Soil Sampling (5 videos)

Getting Started

Visualizing Soil Properties: Preparation (...)

Getting Started: Purpose of soil sampling, tools, preparation to sample, sampling depth, representa
How to Take a Sample

Avoid sampling too soon after rainfall (after heavy rain) or within a few weeks after applying lime, fertilizers, compost or aged manure. You will need:

- A shovel, hand trowel or a soil probe
- A clean plastic container, such as a bucket
- Sampling bags (Ziploc-style bags will work)

1. Sample areas by what is growing there. For example, if you have a garden of mixed vegetables, you need to take a separate sample for each area. If you have a pasture and a garden, take separate samples for each. Areas that have varied characteristics, such as topography, soil moisture, soil type (sandy, clay, or muck), or one area grows poorly, designate separate sample areas for each characteristic.

2. For each sample, take 10 to 15 sub-samples across the whole sample area. Be sure to get even coverage of the entire area. Take randomly located but evenly distributed sub-samples for larger sample areas. Make thin slices of soil, three and twelve inches of soil, depending on the crop and time of year. (See instructions.) Place the sub-samples in your clean containers/bucket.

3. Thoroughly mix the 15 sub-samples and scoop out TWO to THREE CUPS of the soil and place into a bag.

4. Label the bag with your:
   - Name
   - Five letters and/or numbers that will help you remember where the sample came from (such as PST1, GRDN1).

5. If you are taking more than one sample, repeat steps 2-5 for each area.

6. Mail or deliver the samples immediately. Soil nutrient levels continue to change even after a sample is taken, due to microbiological activity. It is critical, therefore, that this activity be stopped as soon as possible after sampling (within 12 hours).

7. Fill out the Soil Sample Information Sheet and mail or deliver samples to:
   King Conservation District
   Attn: Soil Sampling
   1107 SW Grady Way, Suite 130
   Renton, WA 98057

Results are generally available within three weeks and will be e-mailed to you, or sent via postal mail.

<table>
<thead>
<tr>
<th>Guidelines for Sampling Depth</th>
<th>Type of Crop</th>
<th>Sampling Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>For samples taken in September and October</td>
<td>All samples</td>
<td>12”</td>
</tr>
<tr>
<td>Established lawn &amp; pasture</td>
<td>4”</td>
<td></td>
</tr>
<tr>
<td>New lawn &amp; pasture</td>
<td>6”</td>
<td></td>
</tr>
<tr>
<td>Gardens</td>
<td>6”</td>
<td></td>
</tr>
<tr>
<td>Trees &amp; shrubs</td>
<td>8”</td>
<td></td>
</tr>
<tr>
<td>Commercial crops</td>
<td>8”</td>
<td></td>
</tr>
</tbody>
</table>

For samples taken any other time of year

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Each sample should represent one distinct area of land.
Sample should be a slice off the edge of a hole

Soil is biologically active

Refrigerate and mail samples immediately
Each sample needs a unique name. Label the samples well and record where each sample was taken.
An initial snapshot or Tool to measure management progress

### Analytical Results

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (nitrate-N)</td>
<td>14 ppm</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>147 ppm</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>434 ppm</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>1152 ppm</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>196 ppm</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>0.7 ppm</td>
</tr>
<tr>
<td>Sulfur (as SO4)</td>
<td>5.4 ppm</td>
</tr>
<tr>
<td>Organic Matter</td>
<td>5.8 %</td>
</tr>
</tbody>
</table>

### RESULTS

<table>
<thead>
<tr>
<th>Critical Range</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 - 1.0 ppm</td>
<td>Very High</td>
</tr>
<tr>
<td>0.7 - 1.4 ppm</td>
<td>Very High</td>
</tr>
<tr>
<td>0.3 - 0.6 ppm</td>
<td>Very High</td>
</tr>
<tr>
<td>2.5 - 5.0 ppm</td>
<td>Very High</td>
</tr>
</tbody>
</table>

### pH and Lime Requirements

- **Current pH = 5.28** (too acidic)
- **Optimal pH range: 6.0 - 7.0**

### Lime Recommendation

- 54 lbs / 1000 sq ft (1.2 tons / acre)
- Mix the above quantity of ag lime with the top 6 inches of soil. See the following pages for more details.

### Fertilizer Recommendations

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Weight / 1000 sq ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (as nitrate)</td>
<td>2.3 lbs (100 lbs/acre)</td>
</tr>
<tr>
<td>P (as phosphate)</td>
<td>none required</td>
</tr>
<tr>
<td>K (as potash)</td>
<td>none required</td>
</tr>
<tr>
<td>Calcium</td>
<td>none required</td>
</tr>
<tr>
<td>Magnesium</td>
<td>none required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Weight / 1000 sq ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron (B)</td>
<td>none required</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>8 oz (2.5 lbs as gypsum)</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>none required</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>none required</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>none required</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>none required</td>
</tr>
</tbody>
</table>

### N-P-K Fertilizer Options

A fertilizer with N, P, and K in the proportions 20:0:0 is recommended (11 lbs/1000 sq ft). Phosphorus and potassium are already present at high levels. Only a standard annual application of nitrogen is recommended. Below are some organic nitrogen-containing fertilizer options, along with the quantity needed:

- Blood meal - 19 lbs/1000sf
- Scott's Organic Choice - 21 lbs/1000sf
- Feather meal - 21 lbs/1000sf
- Organic urea - 5.0 lbs/1000sf
- Milorganite - 38 lbs/1000sf
Fertilizer and lime (pH) recommendations are tailored to the type of plants to be grown.
pH influences plant growth indirectly through its effects on the solubility of ions and the activity of microorganisms.
<table>
<thead>
<tr>
<th>Potential Soil/Plant Problems</th>
<th>pH</th>
<th>Common Plant Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of drainage, Sodium toxicity</td>
<td>12</td>
<td>Marginal leaf burn</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Chlorosis, Death</td>
</tr>
<tr>
<td>Iron, Zinc, Manganese deficiency</td>
<td>10</td>
<td>Interveinal Chlorosis and Bleaching of new growth</td>
</tr>
<tr>
<td>Aluminum toxicity, Calcium and Magnesium deficiency</td>
<td>9</td>
<td>Reduced Growth and Chlorosis in sensitive plants</td>
</tr>
<tr>
<td>Aluminum toxicity, Calcium and Magnesium deficiency</td>
<td>8</td>
<td>Reduced growth, Chlorosis, Distorted new growth, Necrotic areas</td>
</tr>
</tbody>
</table>

Decreasing Microbial Activity
Levels of macronutrients followed by a graphical interpretation of required levels based on the type of plant indicated by customer.

Nitrogen is sometimes excluded from basic nutrient tests due to a high degree of fluctuation.

Also, commonly, nitrogen is only measured in the form of nitrate.
Caution:
Micronutrients are rarely deficient and the range between deficient and toxic can be very small.

Cultural conditions such as water-logged soils or extremes of pH are more often the cause of chlorosis in plants rather than a deficiency in the soil.
Organic matter improves soil texture, increases water and cation holding capacity and serves as a reservoir of many nutrients.

The ideal percentage of organic matter in soil is debatable and depends on the type of plant material—i.e. cactus vs. blueberries.
High organic matter content

High CEC value
Low organic matter content

Low CEC value
This lab offers fertilizer recommendations in either organic or inorganic options.

Caution: Fertilizer recommendations need to be considered with regard to factors such as season, applications of lime, nearby water feature, etc.
Nitrogen levels tend to fluctuate and test results are not necessarily indicative of total nitrogen availability.

Sulfur levels in soil can fluctuate rapidly which makes test interpretation difficult.
Soil soluble salt levels above 4 mS/cm is considered saline. 

mS= milli Siemens an electrical conductivity measurement

“The soil contains sufficient potassium and phosphorus for the coming year.”

“Nitrogen should be applied annually as a standard practice.”
Generally, 2 inches of proper irrigation can leach 50% of salt from the top 4 inches of soil.
# Heavy Metals Analysis

<table>
<thead>
<tr>
<th>Substance</th>
<th>Measured level in soil sample</th>
<th>Typical levels in soil</th>
<th>Safe Levels</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead (Pb)</td>
<td>12 ppm</td>
<td>3 - 50 ppm</td>
<td>&lt; 400 ppm</td>
<td>Safe</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>0.4 ppm</td>
<td>0.2 - 1.5 ppm</td>
<td>&lt; 10 ppm</td>
<td>Safe</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>0.4 ppm</td>
<td>0.1 - 10 ppm</td>
<td>&lt; 50 ppm</td>
<td>Safe</td>
</tr>
</tbody>
</table>
Common tests for your soil include:

- Nutrient Content (Fertility)
- Salt Content (Salinity)
- Cation Exchange Capacity
- Soil Texture
- pH
- Organic Matter Content
Additional tests available for soils:

- Biological Activity
- Heavy Metals
- Pesticides
- Hydrocarbons
- Irrigation Water Analysis
- Soil Particle Size
- Soilless Mix Analysis
- Water Holding Capacity
- Plant Tissue Analysis

Land use and land history should guide the choice of additional tests.

A good test for solving single plant issues.
Identifies priorities and constraints to inform management practices

Intended to be a guide, not a prescription
Soil Health Analysis

• **Soil Respiration**

  Direct biological activity measurement

  Indicator of cycling of organic matter and mineralization of N
Soil Health Analysis

• **Organic Matter**

  Total organic content of soil- living biomass plus all organic residues

  Key indicator of physical, biological and chemical health of the soil
Soil Health Analysis

• Organic Matter

Can be misleading without qualifying tests

Does not distinguish between stable (old) carbon, active life or new inputs
Soil Health Analysis

• Active Carbon

Food for microbes
Strong indicator of robust soil biological health
Reduced by tillage, increased by composting
Soil Health Analysis

- **Autoclave-Citrate Extractable Protein (ACE)**

  Well associated with overall soil health

  Represents fraction of N-rich OM that is available for mineralization into the soil solution
Soil Health Analysis

• **Aggregate Stability**

  Ability of soil particles to hold together

  Aids water infiltration, microbial health, erosion control, aeration, water storage, root health
Soil Health Analysis

• Soil Hardness Interpretation (compaction)

Surface- measure of water infiltration and erosion prediction

Subsurface- measure of aeration and drainage ability
# Standard Soil Health Analysis Package

**Cost:** $110 per sample  
**Required sample size:** 4 cups  
**Recommended applications:** organic production, vegetable crops, problem diagnosis, home gardens

**Includes these tests:**
- Soil Texture
- Active Carbon
- Wet Aggregate Stability
- Soil Respiration
- Autoclave-Citrate Extractable (ACE) Protein Test
- **Predicted** Available Water Capacity (new for 2019)
- Surface, sub-surface hardness interpretation (Optional: You provide the penetrometer readings.)

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# Extended Soil Health Analysis Package

**Cost:** $170 per sample  
**Required sample size:** 6 cups  
**Recommended applications:** urban/suburban gardens, problem diagnosis, soil health initializing, home gardens, landscaped areas

**Includes Standard Soil Health Analysis Package plus:**
- Add-on Soluble Salts
- Add-on Heavy Metal Screening
- Add-on Root Health Bio-Assay
http://depts.washington.edu/hortlib/index.shtml

Try the Gardening Answers Knowledgebase, a searchable database of Plant Answer Line question/answer sets and recommended websites.

Call the Plant Answer Line at 206-897-5268 (206-UW-PLANT) or email hortlib@uw.edu.