Purpose of Course

Soil and Plant Diagnostics is a short course consisting of 15 lectures. This short course covers soil sampling, soil test correlation, concepts in soil test interpretation, fertilizer recommendations, and plant tissue diagnostics. Plant tissue diagnostics information includes principles of nutrient deficiency identification, interpretation, and DRIS. The short course also includes a lesson that integrates soil and tissue diagnostics. This course emphasizes principles of soil fertility management, the availability of plant nutrients, and their relationship to plant growth and fertilization practices.

This short course is the third in a series of six modules in soil fertility and plant nutrition offered by the University of Idaho. Your comments on this course will be appreciated.
Outline of Course
Soils 446
Module 3: Soil and Plant Diagnostics

Lesson 1: Soil Diagnosis; Soil Sampling
Lesson 2: Soil Sampling; Specialized Soil Sampling
Lesson 3: Specialized Soil Sampling; Soil Test Calibration
Lesson 4: Soil Test Correlation; SLAN and BCSR
Lesson 5: Specific Nutrients: Liming, Nitrogen
Lesson 6: Specific Nutrients: Sulfur, Phosphorus, Potassium
Lesson 7: Specific Nutrients: Micronutrients; Fertilizer Recommendations
Lesson 8: Fertilizer Recommendations
Lesson 9: Plant Tissue Diagnosis
Lesson 10: Nutrient Deficiency Symptoms; Tissue Sampling
Lesson 11: Tissue Sampling / Diagnosis; Orchards
Lesson 12: Tissue Diagnosis: Orchards, Forestry, Interpretation
Lesson 13: Interpretation: Onions, Peppermint; Integration with Soil Sampling
Lesson 14: Integration with Soil Sampling; DRIS
Lesson 15: DRIS
# Table of Contents

Lesson 1: Soil Diagnosis; Soil Sampling ................................................................. 6  
  A. Soil Variability ......................................................................................... 6  
  1. Soil Sampling ......................................................................................... 6  
  B. Sampling Procedures ............................................................................ 8  
     1. Getting a Good Soil Sample ............................................................... 8  
     2. Sampling Depth ................................................................................. 11  
     3. Time of Sampling ............................................................................. 13  
     4. Sample Handling / Shipping ............................................................. 13

Lesson 2: Soil Sampling; Specialized Soil Sampling ........................................... 15  
  5. Nutrient Analysis Requests ..................................................................... 15  
  6. Special Soil Sampling Situations ............................................................. 16

Lesson 3: Specialized Soil Sampling; Soil Test Calibration ............................... 21

Lesson 4: Soil Test Correlation; SLAN and BCSR ........................................... 27  
  SLAN ........................................................................................................ 27  
  BCSR .......................................................................................................... 29

Lesson 5: Specific Nutrients; Liming, Nitrogen ................................................ 32  
  1. Soil Acidity and Liming ......................................................................... 32  
  2. Nitrogen ................................................................................................. 35

Lesson 6: Specific Nutrients: Sulfur, Phosphorus, Potassium ......................... 40  
  3. Sulfur ...................................................................................................... 40  
  4. Phosphorus ............................................................................................ 43  
  5. Potassium ............................................................................................... 46

Lesson 7: Specific Nutrients: Micronutrients; Fertilizer Recommendations ...... 47  
  6. Micronutrients ...................................................................................... 47  
  Fertilizer Recommendations ....................................................................... 50  
     1. Using Fertilizer Guides ...................................................................... 51  
     2. Accuracy ............................................................................................. 52  
     3. Making Recommendations — Examples ............................................ 53

Lesson 8: Fertilizer Recommendations .............................................................. 55

Lesson 9: Plant Tissue Diagnosis .................................................................. 66  
  A. Principles .............................................................................................. 66  
     1. General Picture ................................................................................... 66
Lesson 10: Nutrient Deficiency Symptoms; Tissue Sampling .................................. 74
  2. Nutrient Deficiency Symptoms ............................................................................ 74
  3. Tissue Sampling ..................................................................................................... 76

Lesson 11: Tissue Sampling / Diagnosis .................................................................... 80

Lesson 12: Tissue Diagnosis: Orchards, Forestry, Interpretation .......................... 88
  4. Orchards .................................................................................................................. 88
  5. Forest Fertilization .................................................................................................. 89
  B. Interpretation ......................................................................................................... 92
     1. Using CNR / CNC Systems ............................................................................... 92

Lesson 13: Interpretation: Onions, Peppermint; Integration with Soil Sampling .. 96
  Onions .......................................................................................................................... 96
  Peppermint .................................................................................................................. 98
  2. Integration with Soil Sampling ............................................................................... 102

Lesson 14: Integration with Soil Sampling; DRIS ...................................................... 105
  DRIS ............................................................................................................................ 107
     A. Nutrient Concentration and Aging ................................................................... 107
     B. DRIS Norms ....................................................................................................... 108

Lesson 15: DRIS ......................................................................................................... 112
  C. Making a Diagnosis ............................................................................................... 112
  D. Calculationg DRIS Indcies ..................................................................................... 115
  E. Nutrient Index Interpretation .................................................................................. 116
LESSON 1
Soil Diagnosis
Soil Sampling

Soil Diagnostics

Several factors need to be considered when making fertilizer recommendations. The four most important are:

1.

2.

3.

4.

A. Soil Variability

1. Soil Sampling

(Reading Assignment: Soil Sampling, University of Idaho Bulletin No. 704)

What is a soil test?

► a chemical evaluation of the nutrient-supplying capability of a soil at the time of sampling

What does a soil test measure?

►

►

►
There are four key steps in a good soil testing program:

1. Taking the soil sample

2.

3.

4.

However, without a doubt, soil sampling is the most critical step.

SOILS ARE VARIABLE ! ! !

Research data for 25 soil cores:

<table>
<thead>
<tr>
<th>Soil</th>
<th>P (ppm) Mean</th>
<th>Range</th>
<th>NO₃-N (ppm) Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palouse</td>
<td>6.2</td>
<td>0.1 - 27</td>
<td>5.6</td>
<td>0.2 - 36</td>
</tr>
<tr>
<td>Portnuff</td>
<td>12.6</td>
<td>2.0 - 45</td>
<td>8.6</td>
<td>3.0 - 61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil</th>
<th>S (ppm) Mean</th>
<th>Range</th>
<th>B (ppm) Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palouse</td>
<td>4.2</td>
<td>0.0 - 45</td>
<td>0.5</td>
<td>0.0 - 2.0</td>
</tr>
<tr>
<td>Portnuff</td>
<td>16.4</td>
<td>6.5 - 35</td>
<td>0.4</td>
<td>0.2 - 1.5</td>
</tr>
</tbody>
</table>

To emphasize the importance of good soil sampling think of it this way:

♦ For a P analysis we use 2.5 grams of soil; this represents 2 X 1AFS or 4,000,000 lbs/ac possible from a field as large as 20 acres.

♦ 1 AFS = 2,000,000 lbs X 2 (for 1 foot depth) = 4,000,000 lbs

♦ 4,000,000 X 454 g/lb = 1,816,000,000 grams

♦ X 20 acres = 36,320,000,000 grams of which we determine P on a 2.5 g sample.

♦ Our sample analysis is 7.883 X 10⁻⁸ percent of the soil ! ! !

♦ So a representative sample is very important!
An analysis is only as good as the sample collected

B. Sampling Procedures

1. Getting a Good Soil Sample

a. Map your field

b.

c.

d.
How many samples should I collect?

*Recommended number of soil subsamples to collect from different sized areas*

<table>
<thead>
<tr>
<th>AREA</th>
<th>ACREAGE</th>
<th>MINIMUM # OF CORES</th>
<th>REC #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>4</td>
<td>20</td>
</tr>
</tbody>
</table>
The correct steps involved in soil sampling are illustrated in the figure below:

- Get proper information and materials
- Use proper sampling tools
- Avoid unusual areas for soil samples
- Divide fields into areas for sampling
- Take composite sample from each area
- Use tools properly
- Mix composite sample well
- Fill out information sheets
- Number and record samples
2. **SAMPLING DEPTH**

- Depth of sampling is critical because mobility of nutrients in the soil and tillage can greatly influence nutrient levels in different zones of the soil.

- Since the greatest abundance of plant roots, greatest biological activity, and highest nutrient levels occur in the surface layers of the soil, the upper 12 inches of the soil is used for most analysis.

![Diagram of sampling depth](image)

- Non-mobile nutrients
- When sampling for mobile nutrients take samples by 1-foot increments to the effective rooting depth of the crop.

**Effective rooting depth for some common Idaho crops:**

<table>
<thead>
<tr>
<th>CROP</th>
<th>SAMPLING DEPTH (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals (wheat, barley, oats)</td>
<td>5-6</td>
</tr>
<tr>
<td>Corn</td>
<td>5-6</td>
</tr>
<tr>
<td>Alfalfa, rape</td>
<td>4-5</td>
</tr>
<tr>
<td>Hops, grapes, tree fruits</td>
<td>4-5</td>
</tr>
<tr>
<td>Sugarbeets</td>
<td>2-3</td>
</tr>
<tr>
<td>Peas, beans, lentils, potatoes</td>
<td></td>
</tr>
<tr>
<td>onions, mint</td>
<td>2</td>
</tr>
<tr>
<td>Potatoes, onions</td>
<td>1-1.5</td>
</tr>
<tr>
<td>Vegetable seed</td>
<td>1-1.5</td>
</tr>
<tr>
<td>Gardens</td>
<td>1</td>
</tr>
<tr>
<td>Ornamentals</td>
<td>1</td>
</tr>
<tr>
<td>Forestry - research</td>
<td>1</td>
</tr>
</tbody>
</table>
Sample to one foot for the following nutrients:

Sample to crop rooting depth for the following nutrients:

3. **TIME OF SAMPLING**

- Nutrient concentrations vary with season
- 
- Don’t take samples that are too wet or too dry — tough to get a good representative sample
- 

4. **SAMPLE HANDLING/SHIPPING**

- When you take samples mix them in a plastic bucket if you are requesting a Zn or Fe test
- 

For NO₃ — keep samples cool until they can be dried; if you ship them to a lab — dry them before you ship to prevent denitrification.
LESSON 2
Soil Diagnosis
Specialized Soil Sampling

5. NUTRIENT ANALYSIS REQUESTS

- Only request analyses for nutrients that are known to be deficient in your area. See PNW 276 for details.

- Micronutrient requests for northern Idaho:

  B —

  Mn —

  Mo —

  Zn —

  Cl —

  Fe —

- Micronutrient analyses requests for southern Idaho:

  B —
Mn —

Mo —

Cu —

Zn —

Cl —

Fe —

6. SPECIAL SOIL SAMPLING SITUATIONS

- Special soil sampling problems occur in fields that have been leveled for irrigation or have lost all or most of their topsoil due to erosion; are surface (furrow) irrigated; have had band-applied fertilizer; or are not thoroughly tilled.

a. Land-leveled and eroded areas

  - Areas that have been land-leveled or eroded frequently have little or no original topsoil present and the soil surface may be exposed subsoil material

  - Subsoils —

    —

    —
b. Furrow irrigated fields

- A furrowed field:

- Knowledge of furrow direction, spacing, and location along with closely spaced soil sampling perpendicular to the furrow is necessary to obtain a representative soil sample.
c. Areas where fertilizer has been banded

- When soil sampling is to be done in fields where fertilizers have been banded and the fields are plowed prior to soil sampling, regular sampling procedures can be followed.

- Diagram of banded field:

![Diagram of banded field]

- Options:

  - 
  
  - 
  
  - 

i. Systematic Sampling

![Diagram of systematic sampling]
- take 5 to 10 soil samples perpendicular to the band row beginning in the edge of a fertilizer band and ending at the edge of an adjacent band

- mix and composite samples to obtains a representative sample
  (20 sites x 6 cores/site = 120 cores)

ii. Controlled sampling method

- take 20 to 30 cores scattered throughout

- 

iii. Random sampling method

- use when location of previous season’s fertilizer band is not known

-
Comparison of Soil Sampling Procedures (depth 0-12 inches)

<table>
<thead>
<tr>
<th>Sampling Method</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic</td>
<td>2.9</td>
<td>4.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Controlled</td>
<td>1.8</td>
<td>2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Random</td>
<td>2.5</td>
<td>3.4</td>
<td>2.4</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;.05&lt;/sub&gt;</td>
<td>0.3</td>
<td>0.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

(Source: Mahler, R. L., 1990. Soil sampling fields that have received banded fertilizer applications. Communications in Soil Science and Plant Analysis 21:1793-1802.)
LESSON 3
Specialized Soil Sampling
Soil Test Calibration

d. Reduced or no-till fields

►

► Need special approaches because the soil has been disturbed so that fertilizer is not mixed into the soil

►

► Fertilizer nutrients in the top one-inch of soil will probably not be available to the growing crop

►

► Sample for soil pH by 3-inch intervals:

►

►

►

►

►

►

► Soil pH can affect:

►

►
• weed germination

• plant diseases

The influence of tillage and fertilizer placement on soil pH

<table>
<thead>
<tr>
<th>Depth</th>
<th>No-till</th>
<th>Minimum</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>soil pH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-3</td>
<td>5.0</td>
<td>5.1</td>
<td>5.3</td>
</tr>
<tr>
<td>3-6</td>
<td>5.3</td>
<td>5.0</td>
<td>5.3</td>
</tr>
<tr>
<td>6-9</td>
<td>5.4</td>
<td>5.4</td>
<td>5.3</td>
</tr>
<tr>
<td>9-12</td>
<td>5.8</td>
<td>5.8</td>
<td>5.8</td>
</tr>
</tbody>
</table>


e. Grid Sampling in Non-uniform Fields

- variable rates of nutrients across a given field

GRIDS

- 200 to 300 feet grids for irrigated fields
Results from soil testing labs are worthless unless they can be calibrated against crop response.

In general, there is a high probability of getting a response to a nutrient if the soil test is low.

Initial work — greenhouse
Then apply the nutrient in question in increments (i.e. 0, 30, 60, 90, 120, 150 lbs/ac)

Obtain a graph like:

CRITICAL LEVELS — are determined using the same methodology; however, it's the value above which no response is expected and below which a response is expected.

Ideally:
FOR EXAMPLE: Boron

Critical level:

If sample reads 0.4 ppm -- then:

If sample reads 0.6 ppm — then:

Once greenhouse data is obtained then field work can begin by looking at different soils, climates, and crops; then fine tune numbers for different areas around the state.
CONCEPT: THE LAW OF DIMINISHING RETURNS

Terms:

Maximum Yield —

Maximum Economic and Environmental Yield —
LESSON 4
Soil Test Correlation
SLAN and BCSR

CONCEPTS IN SOIL TEST INTERPRETATION

- Concepts in soil test interpretation differ greatly. All are based on valid principles.
- Any given principle seems to work well under specific conditions, but insufficient research has been done to make one concept applicable to all conditions. We'll talk about the two most important concepts:

PHILOSOPHIES OF SOIL TEST INTERPRETATION

1. SLAN

2. BCSR

SUFFICIENCY LEVELS OF AVAILABLE NUTRIENTS (SLAN)
CONCEPT IN SOIL TEST INTERPRETATION

Implications of Concept:

1. Levels of available nutrients range in a group of soils from insufficiency to sufficiency for optimum growth of plants
2. Amounts of nutrients removed by suitable extractants will be inversely proportional to yield increases from added nutrients.

3.

- Based on Law of Diminishing Returns

**Principles:**

- Mitscherlich’s equation:

  \[ \frac{dy}{dx} = (A-y)c \]

- Yield increases (dy) per unit of available nutrient (dx) decrease as the current yield (y) approaches a maximum yield (A), c, being a proportionality constant.

**Steps in Using Concept:**

1. Selection or determination of sufficiency level based on soil test correlation data.

2.
3.

**BASIC CATION SATURATION RATIOS (BCSR) CONCEPT IN SOIL TEST INTERPRETATION**

- Based on Cation Ratios in Soils

**Implications of Concept:**

1. For optimum growth of crops both a best ratio of basic cations and a best total base saturation exist in a soil

2.

**Principles:**

1. Bonding of cations to exchange sites differ greatly from one type of cation to another, and it differs greatly for the same type of cation at different saturations

2. Amount of exchangeable cations are frequently not proportional to amounts soluble, active, or immediately plant available

3.

4. Both the capacity (total exchangeable) and intensity (activity) of an absorbed cation influence total availability of a cation to a plant
Steps in Using Concept:

1. Selection of basic cation ratios

2.

3. Computation of amounts of Ca, Mg, and K required for proper ratios

4.

BASIC CATION RATIO SATURATION CONCEPT
Situation where SLAN is best

Situation where BCSR is best

Situation where a combination of SLAN and BCSR are best
LESSON 5  
Specific Nutrients: Liming, Nitrogen

1. Soil Acidity and Liming

   a. Status of Soils

   ◆

   ◆ In general, in acid soils Al\(^{+++}\) and Mn\(^{++}\) cause problems with plant growth; H\(^+\) is problem under only the most acid conditions; Acid soils are relatively low in bases (Ca\(^{++}\), Mg\(^{++}\), K\(^+\), etc.)

   ◆

   ◆

   ◆

   ◆ In 1987 24.2 million tons of lime were used in the United States. The lime value exceeded $425,000,000 but was estimated to fill only 30% of the actual need

   ◆ In the Inland Pacific Northwest soils were initially neutral in soil pH; however, many of these soils have become acid.

   ◆ Soil acidification is being caused by N fertilizers:

   \[
   2\text{NH}_4^+ + 3\text{O}_2 \rightarrow 2\text{NO}_2^- + 4\text{H}^+ + 2\text{H}_2\text{O}
   \]

   ◆ See CIS 629: Longterm Acidification of Farmland in Northern Idaho; also see: Communications articles
Critical soil pH values for maximum crop yields:

<table>
<thead>
<tr>
<th>Crop</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>5.0 - 5.7</td>
</tr>
<tr>
<td>Corn</td>
<td>5.0 - 5.5</td>
</tr>
<tr>
<td>Soybean</td>
<td>5.0 - 5.7</td>
</tr>
<tr>
<td>Wheat</td>
<td>5.1 - 5.4</td>
</tr>
<tr>
<td>Peanuts</td>
<td>None; but Ca level imp.</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>5.7 - 6.0</td>
</tr>
<tr>
<td>Grass</td>
<td>5.0 - 5.1</td>
</tr>
<tr>
<td>Grain sorghum</td>
<td>5.3 - 5.5</td>
</tr>
<tr>
<td>Peas/beans</td>
<td>5.5 - 5.6</td>
</tr>
</tbody>
</table>

See CIS 811: *Relationship of soil pH and crop yields*

Idaho data:
The minimum acceptable soil pH values acceptable for crops grown in northern Idaho:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Soil pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lentil</td>
<td>5.65a</td>
</tr>
<tr>
<td>Spring pea</td>
<td>5.52b</td>
</tr>
<tr>
<td>Winter wheat (Stephens)</td>
<td>5.37c</td>
</tr>
<tr>
<td>Winter wheat (Hill 81)</td>
<td>5.31c</td>
</tr>
<tr>
<td>Spring barley</td>
<td>5.23d</td>
</tr>
<tr>
<td>Winter wheat (Daws)</td>
<td>5.19d</td>
</tr>
</tbody>
</table>

b. Correction of Soil Acidity

**LIME** is a material that:

(1)  

and

(2)  

Some commonly used lime materials include:

CaCO₃

MgCO₃

CaMgCO₃
CaO
MgO
Mg(OH)$_2$
Ca(OH)$_2$
Wood ash
Slags

What constitutes an effective liming material?

(1) Chemical composition

(2) Particle size

See *handout on lime material quality*

State Regulations:

<table>
<thead>
<tr>
<th>State laws</th>
<th>Fineness</th>
<th>Minimum</th>
<th>NV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington Fertilizer Law</td>
<td>10</td>
<td>X</td>
<td>CCE</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>X</td>
<td>CaCO$_3$</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>X</td>
<td>MgCO$_3$</td>
</tr>
<tr>
<td>Idaho Fertilizer Law</td>
<td>10</td>
<td>X</td>
<td>CCE</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Oregon Rules</td>
<td>10</td>
<td>X</td>
<td>Lime Score</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
c. Testing Procedures

Lime Requirement Tests:

<table>
<thead>
<tr>
<th>Lime Requirement Test</th>
<th>Number of States</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMP</td>
<td>19 (Oregon)</td>
</tr>
<tr>
<td>Woodruff</td>
<td>4 (Idaho)</td>
</tr>
<tr>
<td>Adams and Evans</td>
<td>4</td>
</tr>
<tr>
<td>Dunn Titration</td>
<td>1</td>
</tr>
<tr>
<td>BaCl₂-TEA</td>
<td>1</td>
</tr>
<tr>
<td>Mehlich</td>
<td>1</td>
</tr>
<tr>
<td>Water pH + texture</td>
<td>3</td>
</tr>
<tr>
<td>Water pH/texture/OM</td>
<td>2</td>
</tr>
<tr>
<td>Base saturation</td>
<td>1 (Washington)</td>
</tr>
<tr>
<td>Al+++ activity</td>
<td>1</td>
</tr>
<tr>
<td>No test</td>
<td>13</td>
</tr>
</tbody>
</table>

◆ Idaho – what is best?

◆ Uses Woodruff (developed in Missouri) easy, simple test

From Blevins: (Soil and Tillage Research 3:135-146)

<table>
<thead>
<tr>
<th>Yearly N Rate kg/ha</th>
<th>--- No till ---</th>
<th>--- Conv till ---</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-5 cm</td>
<td>5-15 cm</td>
</tr>
<tr>
<td>0</td>
<td>5.75</td>
<td>6.05</td>
</tr>
<tr>
<td>84</td>
<td>5.20</td>
<td>5.90</td>
</tr>
<tr>
<td>168</td>
<td>4.82</td>
<td>5.63</td>
</tr>
<tr>
<td>336</td>
<td>4.45</td>
<td>4.88</td>
</tr>
</tbody>
</table>

2. Nitrogen

a. Inorganic Nitrogen

Testing Philosophy

1950s – very limited NO₃-N use

1960s – used in semi-arid regions of the Western US

1970s – tests developed for other areas of the western US and Great Plains
1980s – research begins in the Midwest

1990s – research is underway in humid regions of the US

◆ NO$_3$-N tests are currently used in 19 states

Nitrogen recommendation basis: See handout; see WA Bull #609

Nitrogen recommendation is first based on moisture:

$7.2(SM + R - 4)$

Then base nitrogen rate on yield potential

Today the equation is modified:

Then, the nitrogen recommendation is used to achieve the potential yield:

$2.5 - 2.7$ lbs N/bushel of wheat

So, the nitrogen fertilizer approach is eastern Washington and northern Idaho has been to have the nitrogen recommendation first based on potential yield based on water supply – which is our greatest yield limiting factor:

$7.2(SM + R - 4)$ - Potential Yield

Example problem:

SM = 10 inches
R = 6 inches
What is potential yield?
How much N is required to produce the potential yield?
This work done in the 1950s is still valid today – See *Northern Idaho Fertilizer Guide for Winter Wheat, Table 1.*

Potential Yield = 100 bu

So N need is still based on Leggett’s work from the 1950s.

◆ Given the following information, calculate the amount of N mineralized from organic matter during the season:

  3% OM
  Winter wheat crop (cool season)

Mineralizable Nitrogen: based on calculation

◆ Mineralized Nitrogen = % OM x 2AFS x 0.05 x K

  ▶ By definition:
  
  % OM – from soil test
  2AFS – 4,000,000 lbs
  0.05 – % N in OM
  K – fraction of OM mineralized (1, 2, or 3%)

So a nitrogen recommendation for wheat in northern Idaho and eastern Washington is based on the following:

Total N needed:
(Yield potential x 2.7)  

<table>
<thead>
<tr>
<th>MINUS Mineralizable N</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINUS Soil Test NO₃-N + NH₄-N</td>
<td>-</td>
</tr>
</tbody>
</table>

\[ \text{N fertilizer} = \text{Total N needed} - \text{MINUS Mineralizable N} - \text{MINUS Soil Test NO}_3\text{-N + NH}_4\text{-N} \]
What about N use efficiency?

- If potential yield is 100 bu/ac, we use the 2.7 factor to figure N need (100 x 2.7 = 270 lbs N). However, this assumes 50% nitrogen use efficiency (NUE).

- At 40% NUE:

- At 65% NUE:

What about newer, more efficient N fertilizer materials?

Slow release fertilizers may improve N use efficiency substantially but at present cost at least 35% more on a N unit basis than conventional N materials

A comparison between urea and sulfur coated urea (a slow-release fertilizer):

Urea:
Cost: 0.28 per lb N
50% NUE

To produce 100 bu wheat:
SCU Comparison:

If you increase SCU efficiency to 70%:

Inorganic N Soil Test

Simple procedure
KCl extractable NO₃-N
Reliable test

Mineralizable N Calculation

Based on calculation

b. Organic Nitrogen

◆

◆ Also important in agricultural systems where commercial N fertilizer input is minimal

◆ Excellent, easy test. Currently use CHN analyzer. Loss upon ignition.

◆
LESSON 6
Specific Nutrients: Sulfur, Phosphorus, Potassium

3. Sulfur $SO_4^-$

References:


Tendency for S deficiencies:

a.

b.

c.

d.

e.

◆ The more of the above factors present – the greater the potential S deficiency problems
◆ Northern Idaho / Eastern Washington:
  ◆ factor
  ◆ factor
  ◆ factor
  ◆ factor
◆ Western Washington / Western Oregon:
  ▶ factor
  ▶ factor

◆ Central Washington / Southern Idaho:
  ▶ factor
  ▶ factor
  ▶ factor
  ▶ factor

◆ Note that naturally occurring S in irrigation waters will negate all other factors

*Sulfur Soil Testing Philosophy:*

◆ Sulfate-sulfur soil tests are not widely conducted

◆ Traditionally it was thought that S deficiencies were not widespread in the USA (see handouts and maps)

◆

◆

◆

◆ Most soil test correlation data is to a depth of only 12”

◆

◆

◆ problem also likely related to quality impact rather than yield in many cases

◆ The N:S ratio in plants is about 15:1, based on this

◆ 100 bu wheat requires 270 lbs N
SULFUR RECOMMENDATIONS:

◆ Application rates range from 0 to 25 lbs S/acre in areas known to be deficient in S; rates of 15 to 20 lbs/acre are common

◆ There is quite a bit of current research going on with S in the Midwest, South, and Southeastern USA (coincides with reduced levels of air pollution)

◆

SOIL TESTING – SULFUR:

◆ Poor soil test extractants for SO₄²⁻-S results in poor soil test values

◆ After SO₄²⁻-S extraction, S is determined by one of several methods or instruments:
• Sulfur is important for crop quality – this is not always reflected in crop yield

4. Phosphorus

A lot of soil test correlation research has been done with P

<table>
<thead>
<tr>
<th>SOIL pH</th>
<th>FePO₄</th>
<th>AlPO₄</th>
<th>CaPO₄</th>
<th>Apatite</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Phosphorus Soil Testing

Classification of extractants:

a. Dilute concentrations of strong acids
   
   ▶ very acid (pH 2 to 3)
b. Dilute concentrations of strong acids + a complexing ion


c. Dilute concentrations of weak acids


d. Buffered alkaline solutions

Mechanisms of phosphorus removal by extractants:

a. Solvent action of acids

b. Anion replacement
Common phosphorus soil tests:

<table>
<thead>
<tr>
<th>Soil Test</th>
<th>Extractants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bray I</td>
<td>0.025N HCl = 0.03N NH₄F</td>
</tr>
<tr>
<td>Bray II</td>
<td>0.1N HCl + 0.03N NH₄F</td>
</tr>
<tr>
<td>North Carolina</td>
<td>0.05N HCl = 0.025N H₂SO₄</td>
</tr>
<tr>
<td>(Double acid)</td>
<td></td>
</tr>
<tr>
<td>Trought</td>
<td>0.002N H₂SO₄</td>
</tr>
<tr>
<td>Citric Acid</td>
<td>1% citric acid</td>
</tr>
<tr>
<td>Enger</td>
<td>0.02N Ca-lactate + 0.02N HCl</td>
</tr>
<tr>
<td>Morgan</td>
<td>0.54N HOAc + 0.7N NaOAc</td>
</tr>
<tr>
<td>Olsen</td>
<td>0.5M NaHCO₃</td>
</tr>
</tbody>
</table>

Phosphorus tests in Washington and Idaho:

Acid soils:

Neutral / alkaline soils:

Ca-P
Apatite
Al-P
Status of phosphorus soil test correlation data:

◆

◆

P research needs:

1. Standardization in region for wheat:

<table>
<thead>
<tr>
<th>Soil test</th>
<th>Critical P level</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOAc</td>
<td>4 ppm</td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>10 ppm</td>
</tr>
</tbody>
</table>

2. Correlation between P values for different soil tests

3.

4.

5. Potassium

◆ Often same extractants used for phosphorus are used for K

◆

◆ Not much of a data base in PNW except for potatoes and alfalfa
LESSON 7
Specific Nutrients: Micronutrients
Fertilizer Recommendations

6. Micronutrients

a. Extractants:

1. 

2. The amount of nutrient should be measured with reasonable accuracy

3. 

Examples: DTPA, Mechlich I, etc.
Used for Cu, Fe, Mn, and Zn

b. Boron

► Correlation work is very difficult

► High demand – legumes, fruits, tuber, and root crops

► Boron is mobile in soil – sample to effective crop rooting depth?
Soil critical levels range from 0.1 to 2.0 ppm (hot water extraction) depending on the crop.

In Idaho and Washington the established critical level for low boron demanding crops is 0.3 ppm.

c. Copper

Little field correlation work has been done in the Pacific Northwest.

critical Cu soil test values:

<table>
<thead>
<tr>
<th>Extractant</th>
<th>Critical level (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
</tr>
<tr>
<td>DTPA</td>
<td>0.8</td>
</tr>
<tr>
<td>Mehlich</td>
<td>3.0</td>
</tr>
</tbody>
</table>

d. Iron

A disaster as far as soil test correlation is concerned.
e. Manganese

- As with iron, soil collecting and preparation are critical to obtain meaningful values

- Critical values for Mn:

<table>
<thead>
<tr>
<th>Extractant</th>
<th>Critical level (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
</tr>
<tr>
<td>DTPA (west)</td>
<td>1.4</td>
</tr>
<tr>
<td>Mehlich (east)</td>
<td>7.0</td>
</tr>
<tr>
<td>0.03M H$_3$PO$_4$</td>
<td>10.0</td>
</tr>
</tbody>
</table>

f. Molybdenum

- Few attempts have been made to obtain calibration data

- Molybdenum needed for:

  legumes          nitrogenase
                   nitrate reductase

g. Zinc

-
Idaho, Washington critical levels:

Other critical values for Zn:

<table>
<thead>
<tr>
<th>Extractant</th>
<th>Critical level (ppm)</th>
<th>mean</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTPA</td>
<td>0.8</td>
<td>0.8</td>
<td>0.25-2.0</td>
</tr>
<tr>
<td>Mehlich</td>
<td>1.1</td>
<td>1.1</td>
<td>0.5-3.0</td>
</tr>
<tr>
<td>0.1M HCl</td>
<td>5.0</td>
<td>5.0</td>
<td>2.0-10</td>
</tr>
</tbody>
</table>

Fertilizer Recommendations

- All fertilizer guides are based on extensive research — both field and greenhouse research

- All consultants in Idaho use UI data; differences in recommendations ... UI is much more conservative than consultants

- As new varieties of existing crops and new crops are developed, calibrations need adjustment by doing field research
Need to prioritize research needs in Idaho:

At present the most critical needs for soil test calibration work in Idaho are:

1. Using Fertilizer Guides

Fertilizer guides suggest fertilizer rates based on research results for above average yields

Recommendations assume that other factors are not limiting yield

The efficiency of nutrient use is already taken into account by the fertilizer guidelines (N efficiency estimated at 55%)

There are currently:
2. Accuracy

Fertilizer guides are accurate if:

a.

b.

c.

Recommendations can be based on:

a.

b.

c.
3. **Making Recommendations — Examples**

a. See Soil Test Report #1 (Attached)


Nitrogen:
FLY-BY-NITE SOIL TESTING LABORATORY
SOIL TEST REPORT

Name: Barry Johnson
Address: Troy, Idaho

Field Information (Fill in completely)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Crop</th>
<th>N Fertilizer Applied</th>
<th>Yield (measured or anticipated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next Crop</td>
<td>W. Wheat</td>
<td>90 lbs</td>
<td></td>
</tr>
<tr>
<td>Previous Crop</td>
<td>W. Wheat</td>
<td>80 lbs residue</td>
<td></td>
</tr>
<tr>
<td>199_</td>
<td></td>
<td></td>
<td>returned</td>
</tr>
</tbody>
</table>

Check Tests Desired

Standard Test: Soils Sampling Depth: 12 inches

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>5.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available P (ppm P)</td>
<td>1.6</td>
</tr>
<tr>
<td>Available K (ppm K)</td>
<td>120</td>
</tr>
<tr>
<td>Organic Matter (%)</td>
<td>3.6</td>
</tr>
<tr>
<td>P/K test: NaOAc NaHCO₃</td>
<td></td>
</tr>
</tbody>
</table>

Nitrogen Test:

<table>
<thead>
<tr>
<th>Soil Depth (inches)</th>
<th>Nitrate (ppm)</th>
<th>Ammonium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-12</td>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td>12-24</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>24-36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36-48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>48-60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Soil Fertility Guide:

<table>
<thead>
<tr>
<th></th>
<th>Pounds per acre:</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

Anything unusual about field?

Soil: Severely Eroded

Cation Content: Sampling Depth: inches

<table>
<thead>
<tr>
<th>Cation</th>
<th>meq/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
</tr>
</tbody>
</table>

Sulfur: Result 4 ppm
Boron: Result 0.6 ppm
Copper: Result ______ ppm
Iron: Result ______ ppm
Manganese: Result ______ ppm
Zinc: Result 0.6 ppm
Total Salts: Result ______ ppm
Lime Requirement: Result ______ v/acre

Pounds per acre:

<table>
<thead>
<tr>
<th>N</th>
<th>P</th>
<th>K</th>
<th>S</th>
<th>B</th>
<th>Zn</th>
<th>Other:</th>
</tr>
</thead>
</table>
LESSON 8
Fertilizer Recommendations

Continuation of fertilizer recommendation for Barry Johnson in Troy, ID.

Phosphorus:

Potassium:

Sulfur:

Zinc:
Boron:

Remarks:
b. See Soil Test Report #2 (Attached)

Provide a fertilizer recommendation for B. Ean. B. Ean lives in Twin Falls and wants to grow field corn. Show all calculations.

Nitrogen:

Phosphorus:

Potassium:
Sulfur:

Zinc:

Boron:

Remarks:
FLY-BY-NITE SOIL TESTING LABORATORY
SOIL TEST REPORT

Name: B. Eau
Address: Twin Falls

Field Information (Fill in completely)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Crop</th>
<th>N Fertilizer Applied lbs/N</th>
<th>Yield (measured or anticipated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next Crop</td>
<td>field corn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous Crop</td>
<td>beans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>199_</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>199_</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Anything unusual about field?

Cation Content: Sampling Depth: ___ inches

<table>
<thead>
<tr>
<th>Cation</th>
<th>meq/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
</tr>
</tbody>
</table>

Check Tests Desired

Standard Test: Soil Sampling Depth: ___ inches

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>7.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available P (ppm P)</td>
<td>20</td>
</tr>
<tr>
<td>Available K (ppm K)</td>
<td>130</td>
</tr>
<tr>
<td>Organic Matter (%)</td>
<td>1.5</td>
</tr>
<tr>
<td>P/K test: NaOAc</td>
<td>NaHCO₃</td>
</tr>
</tbody>
</table>

Nitrogen Test:

<table>
<thead>
<tr>
<th>Soil Depth (inches)</th>
<th>Nitrate (ppm)</th>
<th>Ammonium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-12</td>
<td>1</td>
<td>5.6</td>
</tr>
<tr>
<td>12-24</td>
<td>2.5</td>
<td>1.7</td>
</tr>
<tr>
<td>24-36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36-48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>48-60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sulfur: Result: 16 ppm

Boron: Result: 0.5 ppm

Copper: Result: ___ ppm

Iron: Result: ___ ppm

Manganese: Result: ___ ppm

Zinc: Result: 0.55 ppm

Total Salts: Result: ___ ppm

Lime Requirement: Result: ___ %/acre

Soil Fertility Guide:

<table>
<thead>
<tr>
<th>Pounds per acre:</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
</tr>
<tr>
<td>----</td>
</tr>
</tbody>
</table>


c. See Soil Test Report #3 (Attached)


Nitrogen:

Phosphorus:

Potassium:
Sulfur:

Zinc:

Boron:

Remarks:
**FLY-BY-NITE SOIL TESTING LABORATORY**
**SOIL TEST REPORT**

**Name:** Ray Green  
**Address:** Mountain Home

### Field Information (Fill in completely)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Crop</th>
<th>N Fertilizer Applied</th>
<th>Yield (measured or anticipated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next Crop</td>
<td>Irrigated Alfalfa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous Crop</td>
<td>Renew</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td></td>
</tr>
</tbody>
</table>

### Cation Content: Sampling Depth: ___ inches

<table>
<thead>
<tr>
<th>Cation</th>
<th>meq/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
</tr>
</tbody>
</table>

### Check Tests Desired

**Standard Test:**  
**Soil Sampling Depth:** 12 inches

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil pH</td>
<td>7.5</td>
</tr>
<tr>
<td>Available P (ppm P)</td>
<td>42.0</td>
</tr>
<tr>
<td>Available K (ppm K)</td>
<td>50</td>
</tr>
<tr>
<td>Organic Matter (%)</td>
<td>34</td>
</tr>
</tbody>
</table>

P/K test: NaOAc NaHCO3

<table>
<thead>
<tr>
<th>Nitrogen Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Nitrogen Test

<table>
<thead>
<tr>
<th>Soil Depth (inches)</th>
<th>Nitrate (ppm)</th>
<th>Ammonium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-12</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>12-24</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>24-36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36-48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>48-60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Soil Fertility Guide:**

<table>
<thead>
<tr>
<th>Pounds per acre:</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>S</th>
<th>B</th>
<th>Zn</th>
<th>Other:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
d. See Soil Test Report #4 (Attached)

Provide a fertilizer recommendation for Jim Stevens for potatoes in Power County, Idaho. Show all calculations.

Nitrogen:

Phosphorus:

Potassium:
Sulfur:

Zinc:

Boron:

Remarks:
**FLY-BY-NITE SOIL TESTING LABORATORY**
**SOIL TEST REPORT**

Name: Jim Stevens
Address: Power County

<table>
<thead>
<tr>
<th>Field Information (Fill in completely)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
</tr>
<tr>
<td>Next Crop</td>
</tr>
<tr>
<td>Previous Crop</td>
</tr>
<tr>
<td>199</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Check Tests Desired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Test [x]; Soil Sampling Depth: 12 inches</td>
</tr>
<tr>
<td>Soil pH</td>
</tr>
<tr>
<td>Available P (ppm P)</td>
</tr>
<tr>
<td>Available K (ppm K)</td>
</tr>
<tr>
<td>Organic Matter (%)</td>
</tr>
<tr>
<td>P/K test: NaOAc</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitrogen Test [x];</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Depth (inches)</td>
</tr>
<tr>
<td>0-12</td>
</tr>
<tr>
<td>12-24</td>
</tr>
<tr>
<td>24-36</td>
</tr>
<tr>
<td>36-48</td>
</tr>
<tr>
<td>48-60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cation Content</th>
<th>Sampling Depth: inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cation</td>
<td>meq/100g</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sulfur</th>
<th>Result</th>
<th>12 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>Result</td>
<td>0.7 ppm</td>
</tr>
<tr>
<td>Copper</td>
<td>Result</td>
<td>ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>Result</td>
<td>ppm</td>
</tr>
<tr>
<td>Manganese</td>
<td>Result</td>
<td>ppm</td>
</tr>
<tr>
<td>Zinc</td>
<td>Result</td>
<td>0.4 ppm</td>
</tr>
<tr>
<td>Total Salts</td>
<td>Result</td>
<td>ppm</td>
</tr>
<tr>
<td>Lime Requirement</td>
<td>Result</td>
<td>y/acre</td>
</tr>
</tbody>
</table>

**Soil Fertility Guide:**

<table>
<thead>
<tr>
<th>Pounds per acre:</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
</tr>
</tbody>
</table>
LESSON 9
Plant Tissue Diagnosis

A. Principles

1. General Picture

   a.

   b.

   c.

A. Principles

Plant Analysis — is based on the principle that the concentration of a nutrient is an integral value of the factors that have interacted to affect it

1. General Picture

Yield in relation to nutrient supply:
Four distinct zones:

1.

2.

3.

4.

* Can be divided into two subzones:

Sub Zone A — Severe deficiency

♦️

♦️

♦️
Sub Zone B — Moderate deficiency

- May not be able to diagnose deficiency by sight

- often called “HIDDEN HUNGER”

CNR / CNC

CNC — critical nutrient concentration (point)

CNR — critical nutrient range (range)

ADEQUATE —

TOXIC —

1.
2.

3.

a. **Nutrient Concentration Related to Crop Growth**

![Graph showing the relationship between Phosphorus concentration and Relative Yield for Alfalfa.](image)

- Line bends and then plateaus after reaching certain P level

-
A closer look:

![Graph showing nutrient concentration vs yield per unit time]

b. Nutrient Concentrations and Physiological Maturity of the Crop:

- Concentrations of some elements change rapidly with time and physiological maturity. Particularly:
  - Excessive
  - Sufficient
  - Marginal
  - Deficient

- Optimum concentrations of these nutrients change with growth stage of the crop

![Graph showing nutrient concentration vs growth stage]

Growth Stage:
- Early
- Middle
- Late
Idaho Potato Data:

<table>
<thead>
<tr>
<th>Growth State</th>
<th>Petiole Nitrate-N (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant emergence</td>
<td>&gt;</td>
</tr>
<tr>
<td>4 to 8 leaf stage</td>
<td>&gt;</td>
</tr>
<tr>
<td>Hooking</td>
<td></td>
</tr>
<tr>
<td>Early tuber set</td>
<td></td>
</tr>
<tr>
<td>Midseason</td>
<td></td>
</tr>
<tr>
<td>Late season</td>
<td></td>
</tr>
<tr>
<td>Harvest</td>
<td></td>
</tr>
</tbody>
</table>

Nutrient Concentrations and Crop Varieties:

◆

CNC vs CNR:

◆

◆

◆ Inter-relationships with other factors: the uptake of one ion can affect another
Example: Ca and Mg in potato petioles:

- In certain crops, one can diagnose the K status of the crop by knowing the Mg content

C. Other factors:

- Soil moisture
  - Lack of soil moisture may cause lower plant nutrient concentrations in plant tissue — erroneously recommending nutrient additions

- Temperature

- Agronomic Factors
  - Seeding, spacing, liming, etc.
NO$_3$-N in petioles (4 or 5):
LESSON 10
Nutrient Deficiency Symptoms
Tissue Sampling

2. Nutrient Deficiency Symptoms

◆ Only appear under extremely deficient conditions

◆

◆ Identification of plant nutrient deficiency symptoms can help diagnose field problems

◆ The art/science of identifying nutrient hunger signs is a basic step to profitable crop production

FIELD KEY:

I. COLOR CHANGES IN LOWER LEAVES

II. COLOR CHANGES IN UPPER LEAVES

I. COLOR CHANGES IN LOWER LEAVES FIRST:

◆ Lower leaves turn light green to yellow in color, this will quickly spread to the entire plant . . .

◆ Lower leaves exhibit interveinal chlorosis, eventually spreads to entire plant . . .
Lower leaves exhibit brown discoloration and scorching along outer margins of leaves . . .

Lower leaves remain dark green, plant is stunted, in some cases the plant appears purplish in color . . .

Pronounced bronzing of lower leaves, sometimes with interveinal chlorosis . . .

II. COLOR CHANGES IN UPPER LEAVES FIRST

A. TERMINAL BUD DIES

B. TERMINAL BUD REMAINS ALIVE

A. TERMINAL BUD DIES

Emergence of primary leaves delayed; terminal bud dies . . .

New growth is severely deformed, sometimes yellowish or grayish . . .

B. TERMINAL BUD REMAINS ALIVE

Top leaves turn yellow-green, color change rapidly spreads to rest of the plant . . .
- Interveinal chlorosis in new leaves (yellow or white chlorosis) . . .

- Leaves yellowish-gray or reddish gray . . .

- Poor symptoms, young leaves are pale yellow, wilt, leaf margins exhibit brown color

3. Tissue Sampling and Analysis

CONCEPT:

There is a good relationship between nutrient concentration in a crop and the growth and yield of the crop

TISSUE ANALYSIS:

KEY: Choice of tissue to collect and analyze

- Some plant parts are much more sensitive to nutrient changes than others

Petioles:

Potatoes —

Sugar beets —

Upper plant parts:

Alfalfa —

Beans —
Peas/Lentils/Chickpeas —

Lower plant parts:

Wheat —

Oldest leaves of this year’s growth:

Sometimes the tissue choice is AGE or NUTRIENT specific:

CORN:

►

►

►

See WREP 43

►

►

Tissue Sampling Problems:

Dryland —

►
Difficult to add additional fertilizer to correct problems because of the uncertainty of water moving the nutrient into the plant root zone.

Irrigated—

There has been much correlation work done on different crops.

Tissue Sampling and Handling:

A skilled person knows what to look for; can divide fields into separate units; and take good notes!

In order for plant analysis to be meaningful:

1.

2.
In addition, you need to:

a. Take enough samples to represent a field accurately (ie 40 petioles/160 acre field, enough tissue to run an analysis)

b.

c. If a large area (large enough to treat separately) is obviously different, sample it separately
d.

e.

f.

g. Do not sample the edges of the field — there is a definite edge effect!
h. Partially air dry the collected sample — mail to the laboratory in paper bags (most labs furnish these)

◆

◆ Use white bags when requesting micronutrients (brown bags have micronutrient contaminants in the glue)
LESSON 11
Tissue Sampling/Diagnosis

Remember:

Stage of maturity influences the CNC/CNR of an element in a plant. For those plants sampled only once a season — always take the sample during the same growth stage — so samples can be compared year to year!

Tissue Sampling Patterns

Uniform Field

Another uniform field:
Sampling pattern for a non-uniform field:

Additional points to remember:

- Crops sampled at regular intervals during the season should be sampled during the same time of day!

- So nitrate concentrations are higher in the morning than in the afternoon

Interpretation

- Much of the work in tissue analysis is based on calibration (ie 3600 is either deficient or sufficient at X growth stage)

- HOWEVER; there are other parameters to consider when interpreting a tissue analysis

- Incidence of insects or disease
Data handling:

What do we do with data from repeated samplings?

Crop Logging

• Data is plotted graphically and the trends are considered deciding when and/or if additional fertilizer is required
Example 1:

The drawback to only one sampling is in the interpretation — suppose you sample once at midseason:

![Graph showing nitrate-N levels over date/crop stage]

Diagnosis:
If you had previous samples, you could look at the trends and have an easier decision to make. If only 1 point is marginal — do you add N? Too much, too little?

Example 2:

![Diagram showing Petiole Nitrate-N (ppm) over Date/Crop Stage with High and Low lines.]

Diagnosis:
Example 3:

Diagnosis:
Example 4:

Diagnosis:
Example 5:

Diagnosis:
LESSON 12
Tissue Diagnosis: Orchards, Forestry, Interpretation

4. Orchards

- A nutritional program is difficult to establish in orchards because:

1. Soil diagnosis is very difficult

2. Tissue diagnosis also has problems

- Collection of tissue procedures are similar to the information already presented
Some currently accepted critical values for N, P, and K in fruit trees grown in the Pacific Northwest:

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Nitrogen CNR</th>
<th>Excess</th>
<th>Phosphorus CNR</th>
<th>Potassium CNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>1.7-2.0</td>
<td>&gt; 3.0</td>
<td>.1%</td>
<td>.8-1.5%</td>
</tr>
<tr>
<td>Cherries</td>
<td>2.0-2.5</td>
<td>&gt; 3.5</td>
<td>.1%</td>
<td>.8-1.5%</td>
</tr>
<tr>
<td>Peaches</td>
<td>2.5-3.0</td>
<td>&gt; 3.5</td>
<td>.1%</td>
<td>.8-2.5%</td>
</tr>
<tr>
<td>Pears</td>
<td>1.7-2.0</td>
<td>--</td>
<td>.1%</td>
<td>.8-1.5%</td>
</tr>
<tr>
<td>Plums</td>
<td>2.0-2.5</td>
<td>&gt; 3.5</td>
<td>.1%</td>
<td>.8-1.5%</td>
</tr>
</tbody>
</table>

Fruit trees require moderate nitrogen levels, relatively low phosphorus levels, and moderate potassium levels.

Micronutrient requirements:

- Boron –
- Zinc –
- Manganese –
- Copper –
- Iron –

5. Forest Fertilization

Objective of forest fertilization:

1. Increase plant growth
2. 
3. Insect control
4. 
5.

6.

7.

8. Range and wildlife browse values

a. Sampling Tissue

- Relatively straightforward for conifers

Ash leaves and rachi:

<table>
<thead>
<tr>
<th>Plant portion</th>
<th>Nitrogen content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rachi</td>
<td>0.76</td>
</tr>
<tr>
<td>leaf 1</td>
<td>1.1</td>
</tr>
<tr>
<td>leaf 2</td>
<td>2.3</td>
</tr>
<tr>
<td>leaf 3</td>
<td>2.4</td>
</tr>
<tr>
<td>leaf 4</td>
<td>3.4</td>
</tr>
<tr>
<td>leaf 5</td>
<td>2.4</td>
</tr>
<tr>
<td>leaf 6</td>
<td>2.2</td>
</tr>
<tr>
<td>leaf 7</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Conclusion: pick a leaf or rachi; do not composite because the composite could mask problems. Choose either leaf 4 or rachi.
Ash example:

Which species? Which storey?

b. Sampling Position

- This is another problem. Questions:

1. 

2. 

3.
c. Sampling time

- Problems

- 

- 

d. Sample analysis

- 

e. Some Critical Values

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>CNR’s (species dependent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>1.3 - 1.5%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.05 - 0.13%</td>
</tr>
<tr>
<td>Potassium</td>
<td>.3 - .7%</td>
</tr>
<tr>
<td>Sulfur</td>
<td>.1 - .3%</td>
</tr>
<tr>
<td>Calcium</td>
<td>.1 - .4%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>.05 - .15%</td>
</tr>
<tr>
<td>Manganese</td>
<td>no good values 25-2300 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>50 ppm</td>
</tr>
<tr>
<td>Copper</td>
<td>4-6 ppm</td>
</tr>
<tr>
<td>Zinc</td>
<td>8-12 ppm</td>
</tr>
<tr>
<td>Boron</td>
<td>5-8 ppm</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.03-0.06 ppm</td>
</tr>
</tbody>
</table>

B. Interpretations

1. Using CNR/CNC Systems

a. Irrigated Winter Wheat

- Use tissue as an indicator of the nitrogen status of winter wheat cultivars
Sampling:

- Sampling begins when the wheat seedlings reach the 3 or 4 leaf stage

- At least 25 plants should be removed at random from each field

- Later at jointing, the first 2 inches of the stem portion above the ground are used
There is a good relationship between NO₃-N and nitrogen fertilizer rate at given sampling dates.

<table>
<thead>
<tr>
<th>N Treatment (lb/a)</th>
<th>Yield (bu/a)</th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>57</td>
<td>8.0</td>
</tr>
<tr>
<td>40</td>
<td>59</td>
<td>8.0</td>
</tr>
<tr>
<td>80</td>
<td>70</td>
<td>8.9</td>
</tr>
<tr>
<td>120</td>
<td>93</td>
<td>9.5</td>
</tr>
<tr>
<td>160</td>
<td>102</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Results:

- For maximum yields NO₃-N concentrations in leaf tissue should exceed 3,500 ppm at the 3 to 4 leaf stage, and 1,000 ppm at jointing.
All rates: 80 lbs N/ac:

<table>
<thead>
<tr>
<th>Applications Date</th>
<th>Yield (bu/a)</th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/22</td>
<td>70</td>
<td>8.9</td>
</tr>
<tr>
<td>4/5</td>
<td>84</td>
<td>8.6</td>
</tr>
<tr>
<td>4/22</td>
<td>88</td>
<td>9.1</td>
</tr>
<tr>
<td>5/17</td>
<td>82</td>
<td>9.8</td>
</tr>
<tr>
<td>Check</td>
<td>≥ 57</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Results showed that the early spring applications were more effective in increasing yield and tissue NO₃-N.

- Applications made later in the spring, after jointing, increased the NO₃-N content in wheat tissue but were less effective in increasing yield.

- When interpretations and recommendations are made based on NO₃-N levels, remember that factors other than sampling date may influence NO₃-N levels.
**LESSON 13**  
*Interpretation: Onions, Peppermint Integration with Soil Sampling*

b. Onions

- Adequate nitrogen is necessary for maximum onion production, yet excess N can reduce:
  
  - 
  - 
  - 
  - 

**Tissue to Sample**

1. Most recently matured leaf

2.

3.

4.
5.

Tissue Sensitivity:

\[ \text{Nitrate-N} \]
\[ \text{N Rate (lb/A)} \]

\[ \text{Yield (lb/A)} \]

- Roots
- Bulbs
- Necks
- Most mature leaf
- Recently mature leaf

Major problem with onions is that sensitivity is poor
Root NO₃-N levels

- 6,600 ppm NO₃-N in roots when bulbs are ¼ - ½" in diameter

Maximum onion yield are achieved when:

- bulbs —
- necks —
- most mature leaf —
- recent mature leaf —
- roots —

c. Peppermint

- Nitrogen is the nutrient most often responsible for reducing peppermint oil yields in Idaho

Sampling:

- Sampling should begin when the plant reaches a height of 8 to 10 inches and continue periodically until harvest
Part of the plant sampled:

The sample should consist of the top 6 inches of the stem with leaves, petioles, and blossoms removed.

Research:

Critical levels were established using field experiments.
- Levels of stem NO$_3$-N decreased with time, the rate of decline dependent on nitrogen fertilization rate
- Relative oil yield (% of maximum yield) was related to peppermint stem NO$_3$-N levels occurring during the season

**JUNE:**

**LATE JULY/EARLY AUGUST**

Combined Oregon & Idaho data
Relative oil yield did not increase when stem NO\textsubscript{3}-N levels exceeded 4,000 ppm in late June and 2,000 ppm in late July to early August.

Stem NO\textsubscript{3}-N concentrations above 8,000 ppm in early June, 4,000 ppm in early July, and 1,000 ppm in early August are necessary for maximum oil production.

Summary of the three presented examples:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wheat</th>
<th>Onions</th>
<th>Peppermint</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\textsubscript{3}-N or TKN</td>
<td>NO\textsubscript{3}-N</td>
<td>NO\textsubscript{3}-N</td>
<td>NO\textsubscript{3}-N</td>
</tr>
<tr>
<td>Plant part</td>
<td>Stem</td>
<td>Roots</td>
<td>Stem</td>
</tr>
<tr>
<td>Stage of growth</td>
<td>Many</td>
<td>Few</td>
<td>Many</td>
</tr>
<tr>
<td>Critical values</td>
<td>1,000-3,500</td>
<td>6,600</td>
<td>1,000-8,000</td>
</tr>
</tbody>
</table>
2. Integration with Soil Sampling

Earlier example: POTATOES

a. Cropping Systems

- Most important for situations where soil sampling by itself does not provide entirely satisfactory results:

(i) Reduced tillage systems

  ▶
  ▶
  ▶
  ▶
(ii) Perennial Crops

- sod crop  - alfalfa
- pastures  - mint

* situations where fertilizer is topdressed and non-mobile elements (P, K) are concentrated in the surface inches

(iii) Irrigated Cropping Systems
Bernerally:

►

►

►

►
LESSON 14
Integration with Soil Sampling
DRIS

(iv) Fertilizer Banded Fields

▶

▶

▶ potential for integration is good only in higher precipitation areas

(v) Cropping Systems where Fall-seeded Crops receive Spring Applications of Fertilizers

aa. Winter Wheat:

▶

▶

bb. Winter Rapeseed

▶ planted in the fall (before September 1)

▶

▶

▶ high nitrogen demand, but too much in fall reduces winterhardiness

Strategy:

1. Soil test 3 weeks before planting

2.
3.

4. Spring N rate on basis of:

(1)

(2)

Comments: good strategy but there are some gaps ...

1.

2.

3.

b. Environmental Considerations

In the near future:

1.

2. Fertilizers will only be applied to soils when a demonstrated need has been shown

3. Soil sampling will be used not only for fertilizer recommendations but to quantify the levels of nutrients at different depths in the soil, and proximity to the water table

4.

► major work in this area
3. **DRIS**

The Diagnostic and Recommendation Integrated System

- 
  - 
  - 

**A. Nutrient Concentration and Aging**

- 
  - 

- Calcium and magnesium tend to increase in tissue with aging
  - 

- Some have reasoned that since N, P, and K all decrease at relatively the same rate during the season that ratio's will remain constant ... N/P/K ratio constant throughout the growing season
  - 
    -
B. DRIS Norms

1st step:

- DRIS utilizes a survey approach for norm determination that is based on a crop response model:
Because tissue data is not normally distributed:

- The High/Low yield cutoff point is not critical as long as high yield is normally distributed
◆ When comparing nutrient ratios of any two nutrients there are three possible forms of expression:

◆

◆

◆

◆ Use only 1 expression

◆

◆ This is done by comparing the variance of the low-yielding group to that of the high-yielding group. The form of expression (N/P, P/N, or N x P) selected for use within DRIS calculations is that with the largest variance ratio

◆

◆ The forms of expression found that best discriminate between high and low-yielding subpopulations have been selected on the basis of the variance ratio and are N/P, N/K, and K/P
LESSON 15
DRIS

C. Making a Diagnosis:

Use of a DRIS Chart

- In the simplest case the norms of three selected nutrients can be related to one another in a so-called DRIS chart

- The point of intersection of the three axes corresponds to the mean value for the high-yielding population for each form of expression:

- A DRIS chart:

- This is the composition desired in order to increase the chances of obtaining a high yield
A tissue analysis composition falling in the inner circle would be considered balanced and is denoted by horizontal arrows.

The zone of imbalance is divided into 2 subzones:

1. The first zone of imbalance is a zone of slight to moderate nutrient imbalance

2. The second zone is beyond the outer circle; this is a zone of marked imbalance and is denoted by vertical arrows

Example:

<table>
<thead>
<tr>
<th></th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.30%</td>
<td>0.20%</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

N/P = 3.3/2 = 16.5
N/K = 3.3/1.2 = 2.75
K/P = 1.2/.2 = 6.00

Because the excess of one nutrient corresponds to a shortage of another in terms of balance only insufficiencies are recorded by convention for purpose of diagnosis

So:

N/P: lies beyond outer zone giving
N/K: lies beyond outer zone giving

K/P: inside circle

- Once the three common functions are assigned the remaining element gets a horizontal arrow:

- Order or requirement:

- K and P are more limiting than N

Going back to the DRIS chart:
N/P = 16.5
N/K = 2.75
K/P = 6.0
D. Calculating DRIS Indicies

- Diagrams are okay for three nutrients but mathematical expressions should be used for more nutrients

- Initially, standard values or norms must be obtained in a manner previously described. The norms are then used to generate indices by the following equations:

For nutrients A through N:

\[
A \text{ Index} = \frac{\left[ \int \left( \frac{A}{B} \right) \ast \int \left( \frac{A}{C} \right) \ast \int \left( \frac{A}{D} \right) \ldots \ast \int \left( \frac{A}{N} \right) \right]}{z}
\]

\[
B \text{ Index} = \frac{\left[ \int \left( \frac{A}{B} \right) \ast \int \left( \frac{B}{C} \right) \ast \int \left( \frac{B}{D} \right) \ldots \ast \int \left( \frac{B}{N} \right) \right]}{z}
\]

\[
N \text{ Index} = \frac{\left[ \int \left( \frac{A}{N} \right) \ast \int \left( \frac{B}{N} \right) \ast \int \left( \frac{C}{N} \right) \ldots \ast \int \left( \frac{M}{N} \right) \right]}{z}
\]

where, when \( A/B \geq a/b, \)

\[
\int \left( \frac{A}{B} \right) = \left( \frac{A/B}{a/b} - 1 \right) \frac{1000}{CV}
\]

or, when \( A/B < a/b, \)

\[
\int \left( \frac{A}{B} \right) = \left( 1 - \frac{a/b}{A/B} \right) \frac{1000}{CV}
\]

\( A/B \) is the value of ratio of elements in tissue

\( a/b \) is the norm for that ratio

\( CV; \ z \) is the number of functions comprising the nutrient index
For example:

\[ \int \left( \frac{A}{B} \right) = \left( \frac{A/B}{a/b} - 1 \right) \frac{1000}{CV} \]

E. Nutrient Index Interpretation

- Because the value of each ratio function is added to one index subtotal and subtracted from another all indices are balanced to 0

Example: using only N, P, and K:
Corn Leaves:

<table>
<thead>
<tr>
<th>Form</th>
<th>Low Yielding Pop.</th>
<th>High Yielding Pop.</th>
<th>Variance Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>CV</td>
<td>Var $S_A$</td>
</tr>
<tr>
<td>N (% DM)</td>
<td>2.86</td>
<td>20</td>
<td>.326</td>
</tr>
<tr>
<td>P</td>
<td>.30</td>
<td>20</td>
<td>.0036</td>
</tr>
<tr>
<td>K</td>
<td>2.32</td>
<td>27</td>
<td>.392</td>
</tr>
<tr>
<td>N/P</td>
<td>9.88</td>
<td>18</td>
<td>3.158</td>
</tr>
<tr>
<td>P/N</td>
<td>.10</td>
<td>18</td>
<td>.00032</td>
</tr>
<tr>
<td>NP</td>
<td>.85</td>
<td>33</td>
<td>.0792</td>
</tr>
<tr>
<td>N/K</td>
<td>1.39</td>
<td>28</td>
<td>.150</td>
</tr>
<tr>
<td>K/N</td>
<td>.81</td>
<td>24</td>
<td>.0380</td>
</tr>
<tr>
<td>NK</td>
<td>6.59</td>
<td>34</td>
<td>5.040</td>
</tr>
<tr>
<td>K/P</td>
<td>6.94</td>
<td>29</td>
<td>4.000</td>
</tr>
<tr>
<td>P/K</td>
<td>.13</td>
<td>26</td>
<td>.0011</td>
</tr>
<tr>
<td>PK</td>
<td>.71</td>
<td>37</td>
<td>.0675</td>
</tr>
</tbody>
</table>

Sample ratios:

\[
\frac{N}{P} = \quad \frac{N}{K} = \\
\frac{K}{P} = 
\]

Therefore:

\[
\int (N/P) = \left( \frac{N/P}{n/p} - 1 \right) \cdot \frac{1000}{CV}
\]

because $N/P > n/p$.

Inserting proper values:

\[
[(16.5/10.04) - 1][1000/14] = 45.96
\]

for $N/K$:

\[
\int (N/K) = \left( \frac{N/K}{n/k} - 1 \right) \cdot \frac{1000}{CV} \cdot \left( \frac{2.75}{1.49} - 1 \right) \cdot \frac{1000}{CV} = 40.27
\]

For $K/P$ because $k/p > K/P$:

\[
\int (K/P) = \left( 1 - \frac{k/p}{K/P} \right) \cdot \frac{1000}{CV} \cdot \left( 1 - \frac{6.74}{6.00} \right) \cdot \frac{1000}{CV} = -5.6
\]
\[ N \text{ Index} = \frac{\sqrt{(N/P) \star (N/K)}}{2} = \frac{45.96 \star 40.27}{2} = 43 \]

\[ P \text{ Index} = \frac{\sqrt{(N/P) \star (K/P)}}{2} = \frac{-45.96 \star 5.61}{2} = -20 \]

\[ K \text{ Index} = \frac{\sqrt{(N/K) \star (K/P)}}{2} = \frac{-40.27 \star 5.61}{2} = -23 \]

Based on the Index values: