Fertilizer requirements

How much does the plant need?

What is already available?

When does the plant need the nutrient?

How is the fertilizer taken up by the plant?
How mobile is the nutrient?

What source of the nutrient is best?
Mobility in the Plant

- Mobile within the plant
  - N, P, K, Mg, Cl
- Immobile within the plant
  - S, Fe, Mn, Cu, Zn
- Very immobile within the plant
  - Ca, B

Translocation Within the Plant

- Xylem (Water Pipes)
  Dead: Everything goes to leaves with water
- Phloem (Sugar Pipes)
  Alive: To move something out of a leaf requires the phloem

Nitrogen

- Mobile in plant and soil
- Vaccinium plants take up ammonium (NH$_4^+$) form
- N is present in many essential compounds
- General chlorosis along with reddish tinge when deficient; poor growth
- Excess N will increase vigor, may decrease yield & quality
Nitrogen Source

- Blueberry plants use the ammonium form of N (NH$_4^+$)

- Fertilizer programs that contain only nitrate (NO$_3^-$) should be avoided!

- Do not use ammonium sulfate if the soil pH is below 5 unless you add lime

Nitrogen fertilizer rate studies in Vaccinium

Results from applying various rates of N fertilizer in trials with blueberry have been variable throughout world

Variability in results may be partially due to soil fertility, existing plant vigor or age (stored reserves), length of study, and method of fertilization
Nitrogen fertilizer rate studies – Granular

• In 5-year study on ‘Bluecrop’ in Michigan, split applications of 75 lb N/a had higher yield than no fertilizer (Hanson and Retamales, 1992)

• In Arkansas, yield of ‘Collins’, applying 65 or 130 lb N/a reduced yield compared to 20 lb N/a over two years (Clark et al., 1998) and in an 8-year study, there was no benefit to fertilizing with more than 30 lb N/a (Cummings, 1978)

• In Oregon, in a 2-year study in mature ‘Bluecrop’, there was no difference in yield between 0, 100, and 200 lb N/a (Bañados et al., 2006) and
• Fertilization with low to high rate (50 to 240 lb N/a) of N for 7 years in Elliott has had no effect on yield to date (Strik et al)

Nitrogen fertilizer rate studies – Granular

• In Oregon, in establishing plants, the best rate (of 0, 50, 100, and 150 lb N/a) of granular in new fields was 50 lb N/a (Bañados et al., 2006)

• In an organic study in Oregon, the best rate of fish emulsion and feather meal was 25 and 50 lb N/a, respectively, in the first three years of growth. (Larco et al., 2011)
Fertilizer uptake and partitioning ($^{15}$N)
Granular

Nitrogen fertilizer uptake studies using $^{15}$N have been done in field-grown blueberry (Throop and Hanson, 1991; Retamales and Hanson, 1989; Bañados, 2006; White, 2006).

- Plants absorb fertilizer N more efficiently from late bloom through fruit maturity
- Fertilizer uptake efficiency from granular products is low, and thus multiple applications are recommended

Time first application at bloom or early shoot growth
Second application in May

Third application in June
‘Liberty’, 3-year old, Oregon Drip irrigated and fertigated

Southern highbush, three-year-old, in California Fertigated
Nitrogen fertilizer rate studies using fertigation are limited (Bryla, in progress; Finn and Warmund, 1997; Williamson and Miller, 2009)

- In Missouri, northern HB blueberry had larger size and higher yield in year 3 and 4 when fertigated with N compared to same rate of granular N at bud break + 6 or 12 weeks – thought related to improved efficiency (Finn and Warmund, 1997)

- In pine bark system in FL, canopy growth and yield of Misty and Star increased with rate of N fertigated (likely due to limited water and nutrient holding capacity of bark) up to 260 lb N/a and

- Granular (applied monthly Mar-Oct) or fertigation every 2 weeks (Mar-Oct) led to slightly higher yield with granular (Williamson and Miller, 2009)

- In Oregon, granular with ammonium sulfate or urea & micro-spray sprinklers is being compared to drip fertigated at rates from 0 to 225 lb N/a

- In granular applications, high rates lead to high EC (salt) and plant stress

- In fertigated plantings, higher rates of N may not increase yield, but have not lead to salt injury to date

(David Bryla, USDA-ARS, Corvallis, work in progress)
Fertigation (drip) vs. Granular Fertilizer (sprinklers)

Rate and Timing of N application impacts on fruit N

<table>
<thead>
<tr>
<th>Rate of N applied (lb N/a)</th>
<th>N concentration in fruit (%N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.72</td>
</tr>
<tr>
<td>100</td>
<td>0.68</td>
</tr>
<tr>
<td>200</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Soil pH at planting (Apr. 2006) was 6.1.

Vargas & Bryla (unpublished data)
Granular fertilizer
2007
Apr  May  Jun  Jul  Aug  Sep  Oct

NH₄⁺-N (ppm)

Continuous fertigation

0
200
400
600
800
1000

Fertilizer applications

0 lb N/acre
45 lb N/acre
89 lb N/acre
134 lb N/acre

Weekly 4/18-8/15

Electrical conductivity (mS cm⁻¹)

0
1
2
3
4
5
6
7
8

Courtesy: Dr. Dave Bryla, ARS-USDA, 2008
Nitrogen fertilizer rate studies

• N fertilization can increase yield through increased growth however, there is often a threshold

• N fertilization may impact next year's yield through effect on flushes of growth and subsequent flower bud initiation and by increasing winter cold damage
Effect of N fertilization rate of ‘Bluecrop’ at 0.45 m and 1.2 m spacing on shoot growth in 2002

High rates of N force later flush of growth
Late fertilization with N forces late growth
Reduce bud set
Increase cold damage

Bañados and Strik, 2004
Growth rate of whips in Elliott as affected by production system
Year 1

2004 Daily Whip Growth - Pre-Plant Incorporation

White and Strik, 2006
How much N is tied up in fresh sawdust mulch?

- 3" deep 2' wide sawdust mulch centered on rows:

- Fresh sawdust immobilizes 0.1 % N

- = 25 lb N/a

Fresh sawdust (C:N =800) Yang,2005
Adjust N fertilizer when using mulches based on C:N ratio

Weed mat, Duke, Oregon

Bernadine C. Strik, Professor, Oregon State University
Nitrogen (N)

- Mobile in plant and soil
- *Vaccinium* plants take up ammonium (NH$_4^+$) form
- N is present in many essential compounds
- General chlorosis along with reddish tinge when deficient; poor growth
- Excess N will increase vigor, may decrease yield & quality

Phosphorus (P)

- Mobile in plant, but very immobile in soil
- Involved in photosynthesis, other metabolic processes and part of DNA and RNA
- P deficient plants are stunted and often dark green; leaves may have red tinge due to accumulation of anthocyanins
- Excess P will increase root to shoot ratio
**Potassium (K)**

- Mobile in plant, but immobile in soil
- Activator of many enzymes essential for photosynthesis & respiration, and to form starch and proteins; related to osmotic potential and turgor pressure
- Tissue levels related to crop load
- Adequate levels needed for firmness?
- K deficient plants have older leaves with necrotic lesions
- High soil K and low leaf %K often related to production problems

**Magnesium (Mg)**

- Mobile in plant, but immobile in soil
- Present in chlorophyll molecule, combines with ATP, activator of many enzymes essential for photosynthesis, respiration, and to form DNA and RNA
- Deficient plants have older leaves with interveinal necrosis or edges starting red and turning brown
- Deficiencies more common on sandy soil with low pH or if soil K is high
**Sulfur (S)**

- Moves with water in transpiration stream
- Required for protein synthesis
- Deficiency symptoms rare in blueberry due to use of fertilizers with sulfate
- Toxicity often reflected as “salt injury” (see photo)
- Uptake is not sensitive to soil pH

**Calcium (Ca)**

- Immobile in plant and soil; moves in xylem
- Required for cell division, to form cell walls, and normal membrane functions; Ca concentrations in cells are usually kept low by plant to prevent formation of salts; many enzymes are inhibited by high Ca in cells
- Deficiency symptoms in younger leaves; deformed, twisted tissues; low Ca may reduce fruit firmness
- Low soil moisture & cool, cloudy, humid conditions limit %Ca
Test Time!

- Your grandma has osteoporosis?

- Should you feed her lots of lettuce or lots of apples?

- Why?

1 cup fresh lettuce has ~ 10 mg Ca
1 cup fresh apple has ~ 7.5 mg Ca

Iron (Fe)

- Immobile in plant and soil
- Required for chlorophyll formation; forms part of enzymes and proteins
- Fe is internally precipitated in cells or formed into insoluble compounds
- Deficiency symptoms in younger leaves; interveinal chlorosis
- Fe is more available in soil at lower pH & may form insoluble precipitates with excess P
Manganese (Mn)
- Immobile in plant and soil
- More available at low pH
- Required for chlorophyll formation and activation of enzymes; may be involved in auxin regulation
- Deficiency symptoms in younger or older leaves depending on species; interveinal chlorosis
- Toxicity may occur in blueberry.

Boron (B)
- Very immobile in plant; mobile in soil
- Required for normal root tip elongation, cell division in shoot tip; required for normal elongation of pollen tubes
- Deficiency symptoms vary depending on plant species, but may reduce berry size (seed number) and bud break
- Toxicity can occur – tip burning of shoots
- Annual applications, without soil or tissue tests not recommended.
Zinc (Zn)

- Immobile in plant; very immobile in soil
- Required for chlorophyll synthesis and auxin production; required for function of many enzymes
- Deficiency symptoms include little leaf and rosette growth; leaf margins often distorted and leaves puckered; interveinal chlorosis often present
- Zn is more available at low pH

Nutrient accumulation for the whole plant

- New shoots & Leaves accumulate nutrients all season
- Nutrients are lost in leaves at senescence

Losses of N and K in woody tissue in early spring
- Gains in macronutrients in late season
- Nutrients lost with pruning
Nutrient accumulation for the whole plant

Growth of crown and roots occurs in late summer (both) and spring (roots)

Losses of N, P, K, Ca, Mg in crown in early spring, gains in late season

Losses in roots in mid-summer, gains in fall-winter

Nutrients removed in fruit for 9 ton/acre yield. ‘Bluecrop’ as affected by N fertilization rate (avg. 2 years), machine harvest

<table>
<thead>
<tr>
<th>Nitrogen Rate (lb/a)</th>
<th>Nutrient removed with 9 ton/acre yield (lb)</th>
<th>Nutrient removed per 9 ton/acre yield (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N  P  K  Ca  Mg  B  Fe  Mn  Cu  Zn</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>19  3  26  2  1  15  57  76  4  10</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>38  3  28  2  2  14  66  56  4  11</td>
<td></td>
</tr>
</tbody>
</table>
Soil & tissue testing are important to determine fertilizer needs

- Keep records of weather, plant health, fertilization, irrigation, and plant growth
- Adding more fertilizer will not compensate for other limiting factors
- Soil sampling should be representative, reflecting management unit
- Take soil test before planting
- Do soil analysis every 2 to 4 years
- Do annual tissue analysis (to compare to critical values and to establish trends)
- For diagnosis of problems or fixing problems, do both soil and tissue testing

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Unit</th>
<th>Target:</th>
<th>Deficient at less than:</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (in water)</td>
<td></td>
<td>4.5 to 5.5</td>
<td></td>
</tr>
<tr>
<td>Phosphorus (P; Bray)</td>
<td>ppm</td>
<td>25 to 50</td>
<td></td>
</tr>
<tr>
<td>Phosphorus (Olsen)</td>
<td>ppm</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>ppm</td>
<td>100 to 150</td>
<td></td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>ppm</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>ppm</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>ppm</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Boron (B)</td>
<td>ppm</td>
<td>0.5</td>
<td>80</td>
</tr>
<tr>
<td>EC</td>
<td>dS/m</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

na=not available
Why soil pH is important to blueberry production

- Blueberries grow best when the soil pH is between 4.5 and 5.5
- Soil pH is changed by cultural practices such as liming and N fertilizer, especially ammonium sulfate
- Blueberry plants don’t grow well outside optimum pH range.

Yellow plant

Soil pH 6.1 in top 2 inches
Soil pH 5.6 from 2 to 6 inches

Rabbiteye field
Lime induced iron deficiency

Why do blueberries have iron deficiency?

- Iron availability decreases as the soil pH increases
- Blueberries seem to be inefficient at taking iron from soil with a pH above 5.5

![Graph showing soil pH and iron in soil solution](image)
Soil pH influences the root environment by

- Controlling the solubility of toxic materials such as aluminum (Al) and manganese (Mn)

- Reducing the bacterial population that changes ammonium (NH$_4^+$) to nitrate (NO$_3^-$) as the soil pH declines. The NH$_4^+$ form of N has been shown as the only N form blueberries use

- Controlling the solubility/availability of nutrients.
Dr. Bernadine C. Strik, Professor, Oregon State University

High rates of N fertilizer will lower pH. If pH is below 4.2 we see problems.....

Leaf Sampling Concepts

- Leaf concentrations depend on tissue type and tissue age
- Physiological age is more important than a calendar time
- There is no one perfect sample tissue or sample time for all elements
- Procedures used are a compromise
- Pick a procedure and stay with it
- Looking at long term trends is as important as critical values at a given time
Sample most recent fully-expanded leaves in late-July to early August in PNW

Table. Blueberry leaf N sufficiency, late July–mid August sampling

<table>
<thead>
<tr>
<th>Leaf N (%)</th>
<th>Status</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1.50</td>
<td>deficient</td>
<td>13-May</td>
</tr>
<tr>
<td>1.51–1.75</td>
<td>below normal</td>
<td>12-Jun</td>
</tr>
<tr>
<td>1.76–2.00</td>
<td>normal</td>
<td>12-Jul</td>
</tr>
<tr>
<td>2.01–2.50</td>
<td>above normal</td>
<td>11-Aug</td>
</tr>
<tr>
<td>&gt;2.50</td>
<td>excess</td>
<td>10-Sep</td>
</tr>
</tbody>
</table>

Sample most recent fully expanded leaves in late-July to early August

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Deficient below</th>
<th>Sufficient</th>
<th>Excessive above</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>Southern</td>
<td>Rabbiteye</td>
<td>Northern</td>
</tr>
<tr>
<td>Nitrogen (%N)</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Phosphorus (%P)</td>
<td>0.07</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Potassium (%K)</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Calcium (%Ca)</td>
<td>0.2</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Magnesium (%Mg)</td>
<td>0.1</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Sulfur (%S)</td>
<td>0.07</td>
<td>0.1</td>
<td>na</td>
</tr>
<tr>
<td>Manganese (ppm Mn)</td>
<td>10</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Boron (ppm B)</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Iron (ppm Fe)</td>
<td>50</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Zinc (ppm Zn)</td>
<td>4</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Copper (ppm Cu)</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Suggested critical levels for leaf nutrient concentrations (most recent fully expanded leaves) – late July/early Aug; after harvest in PNW

Bernadine C. Strik, Professor, Oregon State University
http://extension.oregonstate.edu/catalog/
Can plants take up nutrients through leaves?

- Plants take up most nutrients through roots, but leaf uptake is possible
- Major limiting factor is how much fertilizer can be added to leaf surface before burning occurs
- It is almost impossible to supply a significant portion of the macronutrient needs of the plant with a foliar program – would require almost constant feeding with low concentrations
- Targeted micronutrient applications can supply a large portion of nutrient relative to plant demand
- For a nutrient to enter the leaf, it must penetrate the cuticle
Efficiency of uptake

• smaller molecules have better penetration
• waxy cuticle is major barrier to movement
• areas near veins, stomata, younger leaves have better penetration
• water stress can lead to thicker cuticles reducing penetration
• low relative humidity and rain reduce efficiency
• formulations important (chelates, buffers, surfactants…)
• every foliar application is a combo of foliar + ground

What about foliar “feeding”?

For N:
Maximum concentration is 5% urea in water (= 14 lb N/a)

In other perennial crops, maximum uptake through leaves + roots has been 50% (= 7 lb N/a)

Foliar applications are sometimes an effective method of correcting micronutrient deficiencies (specific or special situations)
Tunnel production will affect nutrient requirements

Summary

Understanding nutrient mobility is important

Nutrients required are affected by plant age, canopy size, yield, time of year

Fertilizer to apply depends on method of application and amount of nutrient needed

Test for soil nutrient status (pH) and adjust if needed
Tissue testing is important to determine plant nutrient status.

Don’t rely on standards for tissue testing at other times of year.

Goal is to ensure adequate nutrients are available when they are needed (e.g. N for growth; Ca for fruit development and growth; K for fruit; P for root growth).

Choose fertilizer formulations that are best for blueberry.