Spectrum Analytic Inc.

FERTILIZING BLUEBERRIES

Soil Analysis
Plant Analysis
Fertilizer Analysis
Manure Analysis

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Introduction

All blueberries belong to the genus Vaccinium. This genus also includes cranberries, lingonberries, and bilberries. Blueberries are native to North America only. There are four species of blueberries commonly cultivated: Highbush (Vaccinium corymbosum), Lowbush (Vaccinium myrtilloides and Vaccinium angustifolium), and Rabbiteye (Vaccinium ashei). The most obvious differences between the three types of blueberries are in their growth habit. Lowbush varieties typically grow to a height of from 1 to 2 feet. Highbush varieties will grow to a height of from 6 to 13 feet, but are normally pruned to a height between 6 and 8 feet. Rabbiteye varieties can also grow quite tall, but are typically pruned to less than 10 feet tall.

Michigan State University reports that no crop will be harvested the first two years after planting. Properly managed plantings will yield 400 to 800 lb/acre the third season and 1,400 to 2,000 lb by the fourth year. Full crops of 4,000 to 6,000 lb/acre are generally harvested after six to eight years, although mature plantings can yield in excess of 10,000 lb/acre under optimal conditions. Well-maintained blueberry bushes remain productive for at least 15 to 20 years.

Blueberry Rankings by State, 2003					
State	**Rank**	**Harvested Acres**	**State**	**Rank**	**[1/]Yield per Acre (Lb/a)**
Michigan	1	15,400	**Oregon**	1	8,330
New Jersey	2	7,500	**Washington**	2	6,000
Georgia	3	4,600	**N. Carolina**	3	5,360
N. Carolina	4	4,200	**New Jersey**	4	5,330
Oregon	5	3,000	**Indiana**	5	4,170
Washington	6	2,200	**Michigan**	6	3,900
Florida	7	1,900	**Georgia**	7	3,700
New York	8	700	**New York**	8	2,860
Indiana	9	600	**Arkansas**	9	2,820
Arkansas	10	550	**Florida**	10	1,840
Alabama	11	320	**Alabama**	11	1,410

1/ Yields are based on utilized production.

Blueberries have fine, fibrous roots that do not develop root-hairs. All types form symbiotic relationships with mycorrhizal fungi, which aid root functions. Lowbush varieties have most of their roots in the top 3 to 10 inches of soil, while the roots of highbush and rabbiteye varieties reach depths of 30 inches.

Highbush blueberries are the most commercially important, both in cultivated acreage, yield per acre and total tonnage harvested annually. Lowbush blueberries are primarily grown in New England and the Maritime Provinces of Canada. Lowbush blueberry fields are typically wild in origin, rather than having been planted. They are found on shallow, rocky soils typical of their natural range. Lowbush varieties are thought of as being more cold-tolerant, but this might be due to their short height and the natural protection of snow cover that this often affords. Rabbiteye varieties are primarily grown in the Southeast U.S. They tend to be less cold-tolerant and require less chilling to flower successfully.

Highbush blueberries are not very drought tolerant and do best in acid soils with high organic matter, lowbush and rabbiteye varieties require the same acid soils, but are more drought-tolerant and may be less demanding as to soil organic matter. However they will benefit from the same soil conditions as highbush varieties. In recent years breeders have developed some hybrids of highbush and lowbush varieties that combine some of the better traits of each species.

If a new planting is contemplated, the site should be chosen carefully. The soil should have a naturally acid pH, high organic matter, and be near a ready source of irrigation water. Unless otherwise noted, this paper will focus on highbush blueberries.

Nutrient Utilization in Blueberries

In other papers focused on fertilizing a particular crop, we have tried to list the nutrient uptake and removal for as many nutrients as possible. This has proved to be difficult for blueberries due to the limited amount of available data. The USDA has published the following nutrient removal data for blueberries.

NUTRIENT CONTENT OF BLUEBERRY FRUIT (USDA)			
Yield per Acre	Pounds of Nutrient per Yield		
	N	P_2O_5	K_2O
100 lb	0.107	0.023	0.107
1000 lb	1.07	0.23	1.07
6,000 lb	6.42	1.38	6.42
12,000 lb	12.84	2.76	12.84

We were unable to find data for the nutrients contained in the leaves and woody portions of the plant. However, we would logically expect that these values would represent a significant portion of the total uptake of a mature plant. For example with apples and grapes, two crops where there is some data on the nutrient content of the leaves and wood, we can see a rough comparison of nutrient removal vs. the nutrients contained in the woody portions and leaves. It isn't unusual to find that, when compared to the fruit removal values, the wood and leaves contains about 200% of the N, 100% of the P_2O_5, and 125% of the K_20. If these values are applied to blueberries, we find the following.

Assuming that these very rough estimates of the nutrient content of blueberry plants are close enough to use, we cannot therefore assume that when a soil has P and K tests in the desirable ranges that we need only apply removal or even total uptake. There are two reasons for this; 1) the soil does not necessarily release nutrients with 100% efficiency, and 2) plants do not always utilize nutrients 100% efficiently. Often time's lower efficiencies occur due to environmental or other soil conditions. Sometimes environmental conditions contribute to better than expected efficiency as well. Because of these unknowns, the fertilizer program should be evaluated against yield, quality, and leaf analysis over time and revised as necessary.

ESTIMATED NUTRIENT CONTENT OF BLUEBERRY PLANTS				
Yield per Acre		Pounds of Nutrient per Yield		
		N	P_2O_5	K_2O
12,000 lb	**Fruit**	12.84	2.76	12.84
	Bush	38.52	5.52	28.89
Total Uptake		**51.36**	**8.28**	**41.73**

In preparation for this paper, we reviewed the previous three years of plant analysis results for blueberries to identify the most significant nutrient problems. The following table lists the lower and higher limits of the "Normal" range for blueberries and the percent of samples outside of these ranges.

Survey of Blueberry Plant Samples Received by Spectrum Analytic (2002-2004)											
	Percent					**Parts per Million**					
Normal Range	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
From	1.8	0.09	0.4	0.41	0.13	0.11	30	5	60	25	8
To	2.1	0.3	0.7	0.8	0.25	0.16	80	15	200	350	30
% Low	**41%**	**26%**	**15%**	9%	5%	3%	**14%**	**85%**	**33%**	2%	2%
% Normal	33%	**73%**	**67%**	**87%**	**82%**	**50%**	48%	15%	**64%**	**93%**	**87%**
% High	**26%**	0.70%	**18%**	4%	**13%**	**47%**	**38%**	0%	3%	5%	**11%**

Notice that while copper (Cu) is the most common nutrient problem, there are also a significant number of samples that are low in the major nutrients (N, P, K). There are also a large number of low iron (Fe) and boron (B) samples. The large percentage of High S, B, and Zn levels could be misleading because a considerable amount of S is often applied to blueberries to maintain an acid soil pH or as a component of using ammonium sulfate as the N source. Also, a number of producers are applying B or Zn to this crop. There is also some explanation needed for the extremely large percentage of low copper (Cu) results. We wondered if the majority of the low Cu results were "just-barely" low. It turned out that 69% of the Cu results were less than 4 ppm, 35% were below 3 ppm, and about 1% was below 2 ppm. You can see that a lot of blueberry bushes are very low in Copper. Copper is discussed separately later in this paper.

Having discussed blueberry nutrient needs and some examples of where many growers are at this time, let's look at some of the ways to better manage blueberry nutrition. The following two topics on Site/soil Selection and Site Preparation are taken from an article by Ben Fuqua (Ref. 18) who addresses these topics about as well as anyone.

Over the years of working with blueberry producers, the most troublesome problems occur when a grower has planted the bushes in a soil that is not naturally well adapted to blueberries. While adequate sunlight, drainage, and other non-soil test attributes are critical, the most common problem that we see as a soil testing lab is bushes planted in a soil that is not naturally acid. It is very difficult and expensive to acidify soil and maintain the low soil pH. Because of this experience, we have included the following information by Ben Fuqua (reference 18) on the subject.

Site/soil Selection

Selecting a good site for blueberry plants is one of the most important decisions a grower has to make. The large capital investment at the time of establishment and the fact that blueberry plants produce fruit for many years make site selection and site preparation crucial decisions.

An "ideal" site for high-bush blueberries will have a well-drained, low pH soil that has high organic matter content. The site should be exposed to full sunlight, have good air circulation, and have access to water for irrigation. The planting site should also be conveniently located in respect to other buildings or facilities of the blueberry operation.

Site Preparation

Site preparation should start one to two years before planting, as most sites require some slight modification(s) to prepare the soil for growing blueberries. Perennial weeds, such as Johnson grass and Bermuda grass should be completely eradicated by chemical and/or mechanical means. Soil samples should be taken to determine the soil pH and other nutrient levels. Soil organic matter content can be increased by incorporating residues from cover crops, such as Sudan, millet, rye, or wheat into the proposed plant rows. Forming berms or raised beds for the plant rows will improve drainage around the plants. Sulfur, fertilizers, and other amendments needed to correct pH or nutrient deficiencies in the soil should be done at least six months prior to plant establishment.

Soil pH

Proper soil pH is critical to success with blueberries. They require a soil pH in the range of 4.0 to 5.2. This is a strongly acid soil, when compared to most other crops. Blueberries are much less likely to be successful if the soil pH is above about pH 5.5.

Because of blueberries acid soil requirements, they will frequently benefit from soil acidification. This is typically accomplished through the application of sulfur (S). The accompanying table lists some S recommendations for acidifying soil. One note of caution; North Carolina State University recommends that on some of their soils, applications larger than about 300 lb S/a/yr have caused excessive "spikes" in soil pH drop. The soil pH rebounded somewhat from the initial pH drop, but damage can be done by the initial spike. These effects would likely be more common on sandy soils and/or soils with an acid subsoil.

Sulfur Required to Acidify Soil (pounds per acre)

ORIG. pH	TARGET pH	SOIL CEC 1	5	10	15	20	25	35
5.0	4.5	88	175	353	530	665	800	1120
5.5	4.5	175	350	700	1050	1325	1600	2234
6.0	4.5	265	530	1035	1540	1925	2310	3228
6.5	4.5	330	660	1340	2020	2525	3030	4251

Sulfur Required to Acidify Soil (pounds per 100 sq. ft.)

ORIG. pH	TARGET pH	SOIL CEC 1	5	10	15	20	25	35
5.0	4.5	0.20	0.40	0.81	1.22	1.53	1.84	2.57
5.5	4.5	0.40	0.80	1.61	2.41	3.04	3.67	5.13
6.0	4.5	0.61	1.22	2.38	3.54	4.42	5.30	7.41
6.5	4.5	0.76	1.52	3.08	4.64	5.80	6.96	9.76

The soil acidification tables are limited to an original soil pH of no higher than pH 6.5 because soils with a higher pH are not recommended for blueberry production.

If you are thinking about establishing a new blueberry planting, you can avoid much grief and expense by selecting a soil that is naturally acid to begin with.

Sulfur (S) is widely known to be useful in acidifying soil, but it is not the only material that will reduce soil pH. As the accompanying table shows, S is the most powerful acidifier. However, it requires bacterial action to create the acid. The speed of this bacterial action is relatively slow because it is regulated by temperature, moisture, and other factors that control bacterial life processes. This means that acidification occurs primarily in the warmer months. Some of the other materials, such as aluminum sulfate, iron sulfate, or sulfuric acid are chemical reactions and are normally much faster.

COMMON ACIDIFYING MATERIALS

MATERIAL	CHEMICAL FORMULA	PERCENT SULFUR	LBS OF MATERIAL TO EQUAL 100 LBS OF SULFUR
SULFUR*	S	99.0	100
SULFURIC ACID	H_2SO_4	32.0	306
SULFUR DIOXIDE	SO_2	50.0	198
IRON SULFATE	$FeSO_4 \cdot 7H_2O$	11.5	896
ALUMINUM SULFATE	$Al_2(SO_4)_3$	14.4	694
AMMONIUM SULFATE*	$(NH_4)2SO_4$	23.7	422

***NOTE:** The acidifying effect of elemental sulfur is caused by sulfur oxidizing bacteria. These bacteria must be present in the soil, in sufficient amounts, in order to have the desired effect. If a soils pH is above 7.2 in its natural state. it may not have a large population of sulfur oxidizing bacteria. In these cases it may be helpful to inoculate it by adding some soil from another source that is naturally acid. Also, the pH change caused by the bacterial oxidation of sulfur may be relatively slow (12 months or more) since they are dependent on sufficient soil moisture and temperature to accomplish efficient sulfur oxidation. The other products listed produce a chemical acidifying effect, independent of soil organisms and may be faster and more dependable than elemental sulfur..

Most N fertilizers also act as acidifying agents. However, acidic fertilizers are rarely powerful enough to be the sole source of acidifying material in a blueberry soil. The accompanying table lists the

CALCULATED EQUIVALENT ACIDITY OF COMMON NITROGEN MATERIALS

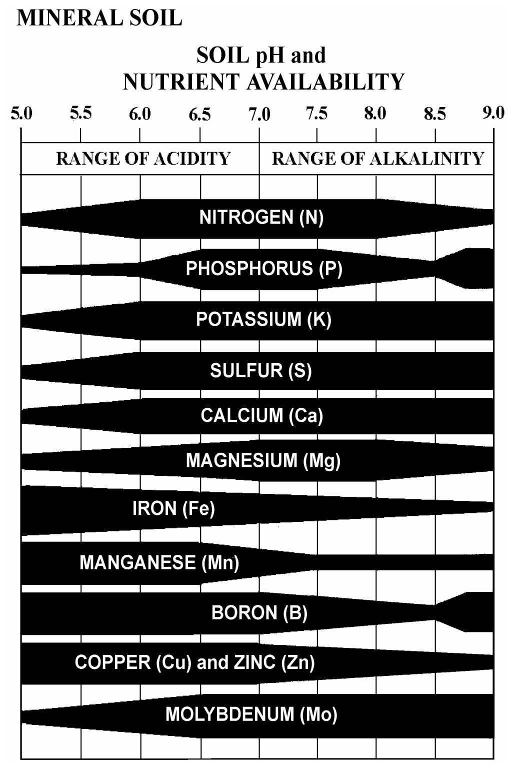
N SOURCE	% N	CHEMICAL FORMULA	100 LB OF NITROGEN*	100 LB OF FERTILIZER*
Ammonium Sulfate	21	$(NH_4)_2SO_4$	535	151
Anhydrous Ammonia	82	NH_3	180	295
Ammonium Nitrate	34	NH_4NO_3	180	122
Urea	46	$CO(NH_2)_2$	180	166
UAN	28-32	$CO(NH_2)_2+NH_4NO_3$	180	101-115
Calcium Nitrate	15	$Ca(NO_3)_2$	135B	20B
Sodium Nitrate	16	$NaNO_3$	180B	29B
Potassium Nitrate	13	KNO_3	200B	26B

Adapted from the Potash and Phosphate Institutes Soil Fertility Manual

* Pounds of calcium carbonate ($CaCO_3$) needed to neutralize the acidity formed from 100 pounds of nitrogen, or nitrogen containing fertilizer. The "B" denotes a basic (pH increasing) effect. These are theoretical values and may differ somewhat in actual soil.

relative acidifying properties of some common N sources. The N fertilizers with a B beside the equivalent N or equivalent fertilizer number have a basic reaction that tends to increase the soil pH. Keep in mind that blueberries do not do well with fertilizers containing nitrate forms of N (NO_3-N), so blueberry producers are limited to the ammonium or urea containing materials (see following section on nitrogen for more information).

Since lime is rarely needed on blueberry soils, there is little information on the amounts of lime that may be needed in those rare occasions when the soil pH is below pH 4.0. In 2000 researchers in New Jersey looked at lime requirements to increase the pH of blueberry soils that had an initial soil pH of between pH 3.3 and 3.9 to a target range of pH 4.3 to 5.0. These soils were sandy to loamy soil types (low to mid CEC ranges). They found that on average, it took about 100 lb/a of $CaCO_3$ to raise the soil pH 0.1 unit. While they did not look at other soil types, we can safely assume that soils with a significant amount of clay in them (clay-loam, loamy clay, clay) would require more $CaCO_3$ for an equal effect. However, this work suggests that if lime is to be applied to blueberry soil, you probably don't want to apply more than 500 lb/ac on sandy or loamy soil. A new soil sample should be taken 12 to 18 months after each lime application in order to avoid over-liming the soil. Clay soils would require more CaCO3 to have a similar effect, but we would suggest an upper limit of 750 lb/ac of $CaCO_3$ per application, and then re-test the soil.



While blueberries require a very acid soil for proper growth and yield, the same acid soils can cause some other nutrient problems. As can be seen in the chart "Soil pH and Nutrient Availability", the 6 primary/major and secondary nutrients are much less available in the 4.0-5.2 pH range for blueberries. However, several of the micronutrients are exceptionally available, possibly to the point of toxicity in some cases. Fortunately, blueberries evolved in these conditions, and are well adapted to the shortages or excesses of acid soil. Sometimes, in spite of these adaptations, blueberries need special fertilizer rates or types due to the acidic soil conditions and the nature of blueberry physiology.

Manure on Blueberries

We have had a couple of inquiries about the benefits or concerns with applying manure on blueberries. We advised against applying fresh manure on blueberries. While manure is not inherently bad for blueberries, it could cause problems in a couple of ways. First, manure contains chlorides (Cl) that can be damaging to blueberries in relatively small amounts. A grower might not have problems with Cl the first time or two that he uses manure, but given the right conditions, he runs the risk of Cl damage at some time. Secondly, with manure the grower has little control of the timing or form of nitrogen (N) that the crop finds available in the root zone. With manure, a grower risks supplying the crop with too much nitrate-N (NO_3) and not enough ammonium N (NH_4). Blueberries cannot efficiently utilize nitrate-N (see following comments in section on N). Later, as the organic N in manure breaks down, there will be more ammonium N becoming available. Ammonium N is utilized by blueberries, but the timing of the N availability to the crop may not match the timing of the N demand by the crop. Finally, manure may release a significant amount of useful N late in the season. When this happens, the bushes could go into the winter in a very soft condition and suffer unacceptable freeze damage. Because of these uncontrollable risks and the fact that blueberries don't have a high demand for N in the first place, we suggest that growers stick to using more controllable commercial fertilizer.

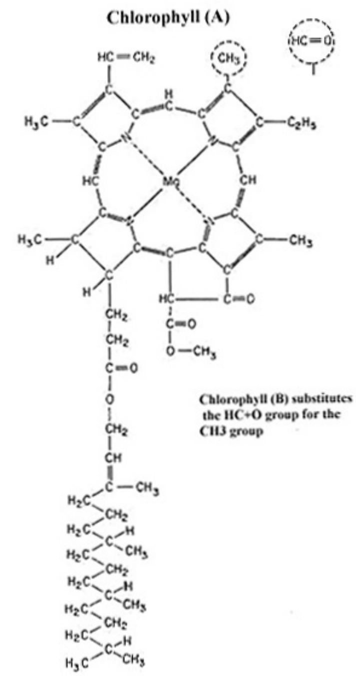
General Comments on Fertilizer Application

Spectrum Analytic recommendations are based on fertilizer applications to an entire acre. However, many blueberries receive some form of banded fertilizer. This presents an opportunity for possible modifications to our recommendations. First, the fertilizer recommendation should probably be adjusted for the amount of land that actually receives fertilizer. For example, if fertilizer is applied in two broad bands (for example, 12 inches wide) on either side of a row, and the row width is 10 ft, then the actual amount of land that is fertilized is only 20% of the entire acre (2 ft out of every 10 ft). This means that you may not need to apply the entire amount of fertilizer recommended. Theoretically, you would only need to apply 20% of the recommendation. However, this theoretical rate adjustment will not likely be correct. Growers are strongly encouraged to adjust their N applications according to leaf analysis results and crop performance.

Blueberry producers also have the opportunity to use foliar fertilization to make in-season adjustments to their crops nutrition. Foliar fertilization is not a replacement for a sound soil fertility program. It is only useful as an additional option to fine-tune the crops nutrient status during the growing year. Foliar fertilizer is typically most applicable to micronutrients. However, it isn't unreasonable to "tweak" the levels of N, P, K, Ca, Mg, or S in the plant with a timely application of these major and secondary nutrients, if leaf analysis indicates a need. Foliar fertilizer is not likely to be the complete answer to a severe shortage of a major or secondary nutrient.

Nitrogen (N)

Function of N in Plants



Nitrogen is a structural component of several essential plant parts and compounds. They include...

1. Chlorophyll (note central Mg atom connected to 4 N atoms)
2. Nucleic acids (DNA, RNA) in each cell
3. All proteins

As a result of these functions, corrections of N shortages result in large gains in vegetative growth, much higher protein levels, and much higher yields of grain, fruit, and vegetative plant organs. While these gains are normally desirable, excess amounts of N, either in absolute terms or sometimes in the ratio of N to other elements, can have a negative impact on some aspects of various yield components.

Nitrogen Deficiency Symptoms

1. Shorter new shoots
2. Sometimes only one flush of new growth
3. Few new canes
4. Chlorotic leaf color (pale green or yellow-green leaf color), developing on the older leaves first.
5. Early fall leaf coloration and leaf drop
6. Reduced yield

N Sufficient **N Deficient**

Nitrogen Toxicity or Excess

Nitrogen is not normally thought of as having a toxic effect on plants. However, excess N can have negative effects on plant performance. Visual symptoms of excess nitrogen include:

1. Excessive shoot growth
2. Larger than normal, dark green leaves
3. More growth flushes than normal, with the last one too late to harden-off before winter. The tips of these later shoots often are killed by low temperature.
4. Typically lower yields of small, late-ripening berries
5. High ratios of N to other nutrients (especially K) within the plant tissue can lead to increased susceptibility to damage from diseases, insects, and adverse environmental conditions like dry weather.

NO3-N **NH4-N**

Blueberries, and their relatives' cranberries, lingonberries, and bilberries have somewhat unique N requirements. They are not able to use nitrate forms of N (NO_3-N) effectively. These plants have evolved in soil conditions that do not naturally contain a significant amount of NO_3-N and they depend more on ammonium-N (NH_4-N). Blueberries take up both forms of N, but they have limited nitrate reductase activity. Nitrate reductase is an enzyme that is needed to convert nitrate to amino acids and proteins. The limited nitrate reductase system in blueberries means that they cannot efficiently utilize nitrate forms of N. Some reports also state that excessive nitrate fertilization can lead to leaf burn. Two recommended N sources include ammonium sulfate and urea, which either contain or form ammonium-N after application.

Spectrum Analytic recommendation is a flat 65 lb. N/ac for blueberries. We don't distinguish between young plants and mature ones because we simply have no practical way of identifying the age of the planting and adjusting the N recommendation accordingly. However, we agree that young plants should receive less N than mature ones. Some authorities recommend N rates up to 140 lb. N/ac for mature plants. Most of the highest N recommendations are located in the Western states. The following table gives an example of some N recommendations made by various University Extension services.

Year	New England NRAES-55 N (lb/a)[2]	Mich. N (lb/a)[3]	N Carolina N (lb/a)[4]	Avg. for MW & East N (lb/a)	Pacific NW PNW 215 N (lb/a)[1]	Idaho N (lb/a)[1]	Avg. for West N (lb/a)
1	0	0	16	5	10	26	18
2	15	15	32	21	20	39	30
3	20	15	78	38	30	53	42
4	27	30	78	45	50	66	58
5	35	30	78	48	60	66	63
6	45	45	78	56	70	66	68
7	55	45	78	59	90	66	78
8+	65	65	78	69	100	66	83

1 Assumes 1000 plants per acre
2 Split application between bud break and 6 wks later. Recommended N rates are about 30% higher in Southern areas, and fertilizers should be split over a 12 week period after bud break. In the Pacific NW, rates are 50%-100% higher.
3 No recommendations or explanations listed for years 1,3,5,7, so rates assumed to be the same as previous year.
4 Apply 36-60 lb. N/a after first flush of growth and 30 lb N/a 4-6 weeks later.

Spectrum Analytic strongly recommends that blueberry producers use annual leaf analysis to develop and adjust their fertility programs for highest yield, quality, and profits for their particular conditions.

Work at Rutgers found that there is little need for fertilizer before bud break. They report that fertilizer applications made after the beginning of active leaf and shoot growth can be ten times as efficient as fertilizer applied prior to bud break. However, P and K that is not taken up immediately will contribute to the soil test level and be taken up later, so it is difficult to see a good reason not to apply these nutrients preplant.

Blueberries are often mulched with organic materials. Where good compost is used, it can contribute to the crops nutrition. However, mulching with sawdust or wood chips will likely tie up N as bacteria begin the decomposition process. This can result in an N demand that is as much as double the normal recommendations.

Blueberries are shallow-rooted and can absorb N quickly. Multiple, split applications will often increase the efficiency of N use, particularly on sandy soils where N can easily leach out of the root zone before bushes can use it. Michigan suggests that the annual N requirement can be split into two or three equal portions applied in May and June. They also warn not to fertilize plants later than July because it may stimulate late growth that is prone to winter injury.

Some growers prefer to supplement annual soil applications of N with foliar sprays during the season. Supplemental N sprays may benefit N deficient bushes, but bushes receiving appropriate soil applications of N are unlikely to show a yield response to foliar N applications.

Phosphorus (P, P_2O_5)

Function

1. Structural component of proteins, enzymes, nucleic acids, and DNA
2. Photosynthesis (production of sugars and starches)
3. Respiration (producing energy by oxidizing sugars and starches)
4. Energy storage and transfer
5. Cell division and enlargement

Some of the benefits of adequate P nutrition include...

1. Early root formation and growth
2. More abundant flowering
3. Better fruit quality
4. Better growth in cold temperatures
5. Better water use efficiency
6. Proper maturation of fruit

Phosphorus compounds form part of the structure of amino acids, proteins, nucleic acids, and DNA. Amino acids form proteins, which are the building-blocks of many structures that plants are made of. Without nucleic acids plant cells cannot develop or function properly. Obviously, without DNA plants cannot reproduce, which means that they cannot produce the fruit that we harvest.

Less obvious are the many different roles that various proteins play in the proper functioning of plants. For example, some proteins are essential for the formation and proper function of enzymes, which are involved in many plant processes, including photosynthesis.

Phosphorus plays a central role in both photosynthesis and respiration. The production of sugars during photosynthesis and the conversion of these sugars into energy during respiration enable the plant to perform all other life-functions. When respiration is restricted due to a P shortage, sugars are not converted into energy and they accumulate within the plant tissue. The accumulation of unused sugars leads to the purple coloration often seen with P deficiency. The low energy level within the plants is the underlying cause of the stunted growth typically seen with P deficiency. When energy is low, all plant processes suffer. Flowering and reproduction place a high demand for energy on plants (not to mention the need for DNA in seed and fruit production after fertilization). Therefore, adequate P is essential to the process. A plants ability to generate abundant energy becomes more important when it is put under additional stress, such as cold soil and air temperatures.

FACTORS AFFECTING P AVAILABILITY

At the risk of stating the obvious, the soil test P level is typically the most significant factor controlling P availability to crops. However, P availability can be strongly affected by several other soil factors.

1. **Soil pH:** The strongly acid soil required by blueberries reduces the solubility (availability) of soil P. As the soil pH decreases below about pH 6.0, soil P is increasingly “fixed” into less soluble forms by excess soluble aluminum (Al) and iron (Fe).
2. **Soil Compaction:** Phosphorous moves very little in the soil. Because of this, plant roots must be healthy and actively explore new areas of the soil daily in order to obtain adequate amounts of P. Anything that inhibits aggressive root growth is likely to reduce P uptake, even in high P soils.
3. **Soil Aeration:** Inadequate soil aeration is often related to soil clay content, soil drainage, and soil compaction. Blueberries, like most cultivated plants require adequate oxygen (O_2) in the soil atmosphere. A lack of adequate soil O_2 can reduce P uptake by as much as 50%.
4. **Soil Moisture:** As plant stress from low soil moisture increases, P availability and uptake decrease. Higher levels of soil P result in higher P uptake at all moisture levels. However, as soil moisture begins to exceed field capacity, the excess water excludes the needed oxygen from the soil and P uptake begins to suffer due to the lack of O_2 in the soil.

5. **Soil Temperature:** Cold soil reduces chemical activity in the soil and biological activity in plants. This results in less P uptake. As the summer begins to warm up both soils and plants, uptake efficiency improves. However, permanent yield losses can occur from early season P shortages.

6. **Soil Texture:** Generally, low CEC soils (more sand, less clay and organic matter) often require higher soil P tests to supply equivalent amounts of P to a crop. Such soils typically hold less water at any point in time, which slows P diffusion to the roots. These soils also have less particle surface area and it appears that current soil testing procedures may extract a higher percent of the total P in lower CEC soils. This would lead to less capacity to quickly replenish the P in solution (buffering power) and require a proportionately higher soil P level for equivalent P supplying power. Some clay types have a high P fixation capacity. These types of clay are more common in tropical soils. In these cases, we would logically expect a higher CEC to require a proportionately higher soil P level for adequate soil fertility.

7. **Soil Organic Matter:** The organic matter (OM) in soil may account for anywhere from 3% to 75% of the total P in a soil (not necessarily the same as "available P"). Generally, increased OM results in greater fixation of Fe and Al, resulting in less P fixation by these elements, and more available P. Such reactions also tend to reduce the fixation of applied P as well. Typically, in soils developed in temperate climates, the contribution of P by OM is relatively small and the main source of P for plants is the inorganic forms.

8. **Crop Residues:** Incorporation of large amounts of crop residues can result in immobilization of available P by microbes. As they decompose the residue, they grow and reproduce, thus creating their own need for available P. During the decomposition of crop residue, soil microbes are effectively in competition with higher plants. Microbially immobilized P will gradually become available as decomposition is completed, the microbes die, and they are re-cycled (mineralization). Factors such as temperature, moisture, soil pH, soil aeration, and the availability of other nutrients have a direct bearing on the level of microbial activity in the soil and the rates of immobilization and mineralization. While this cycle is present in all soils, it is not thought to be a reason to make significant adjustments in fertilizer recommendation programs.

9. **Plant Root Systems and Mycorrhiza Fungi:** Blueberries have a somewhat unique root system. The roots do not have "root hairs" like most other crops. Root hairs are single cell extensions from the root surface that greatly increase the absorption surface of the root, and therefore absorption capacity of the roots. The lack of root hairs on blueberry roots would be a serious disadvantage to survival, especially in the uptake of immobile nutrients like P, except for an adaptation that the species has evolved. Blueberries have compensated for the lack of root hairs by evolving a symbiotic relationship with vesicular-arbuscular mycorrhizal (VAM) fungi in the soil. Mycorrhizae are soil fungi that form a symbiotic association with plant roots. The thread-like hyphae of the fungus connect with plant roots and extend into the soil. The hyphae act like extensions of the plants root system by absorbing nutrients and transporting them back to the plant roots. In exchange, the mycorrhizae receive sugars manufactured by the plant. A major benefit for the blueberries is an improvement in P uptake.

    While mycorrhizae can infect most plants, they typically are more of a benefit to woody species than agricultural row-crops or forages. It has been demonstrated with agricultural crops that the benefits of mycorrhizae decrease as the soil P level increases. In flooded soils, mycorrhizae may die. If the soil has a low level of available P, the loss of the Mycorrhizae may greatly decrease the crops ability to absorb enough P. This effect has been seen in wheat following flooded rice crops.

10. **Soil P Test:** As mentioned earlier, soil P is essentially immobile, and the portion of soil P that is soluble and immediately available to plants is exceptionally small. Therefore, plant roots (and VAM fungi, in the case of blueberries) must constantly explore large volumes of soil to satisfy their need for P. Spectrum Analytic's optimal soil P level is higher for blueberries than for some other crops. However, this is more a function of the acid soil pH required than other factors.

INTERACTIONS

1. **Nitrogen (N):** It is well known that increased N uptake stimulates the uptake of many other elements, including P. Many observations with typical agricultural row-crops have found that P uptake is enhanced when applied in combination with ammonium-N (NH_4-N) as opposed to nitrate N (NO_3-N). This benefit typically requires that the N and P be applied in either a chemically combined form or as a concentrated mixture, such as

a banded fertilizer blend. The exact mechanism for this reaction is not clearly understood. However, it is thought that as the NH_4-N undergoes nitrification, P uptake is increased. Having said this, it is not clear that this N-P relationship would necessarily apply to blueberries or other crops grown in strongly acid soils. In these soils, little nitrification occurs (see N section). However, since blueberries have adapted a preference to ammonium-N, this is probably a moot point. Ammonium-N is the most effective N source for the crop and should be the N source applied, regardless of any benefits, or lack of benefits to P uptake,

2. **Potassium (K):** Potassium has been shown to co-precipitate with P when soluble phosphatic fertilizers are applied to soils. This effect is more pronounced in soils with high exchangeable K levels or with easily decomposed K-bearing minerals. However, this reaction has rarely been demonstrated to have a significant effect on plant growth and there is no reason to adjust recommendations because of this. There is little or no evidence to show an interaction between P and K within the plant.

3. **Calcium (Ca):** As mentioned in the section on pH, at high soil pH, Ca will combine with P to make insoluble compounds that are unavailable to plants in the short term. This is not a concern for blueberries when the soil pH is correct.

4. **Magnesium (Mg):** Phosphorus and Mg are often highly reactive in fertilizer manufacturing processes. The result of this reaction is the formation of highly insoluble compounds that coat or clog equipment. However, this effect has not been demonstrated to be a concern in the soil. In fact, much work has shown that Mg fertilization can enhance P uptake by plants. Within plants, Mg is an activator of certain enzymes that are critical to P transfer and as such, proper Mg nutrition would be essential to the uptake and utilization of P within the plant.

5. **Sulfate Sulfur (SO_4-S):** There has been some work that suggests that sulfates (SO_4-S) may compete with soluble phosphates ($H_2PO_4^-$) for the limited amount of anion retention sites in soil. These retention sites appear to primarily be Al and Fe hydroxides. The effect of such a relationship would be that high applications of either S or P might displace the other. In theory, this would cause a short-term increase in the amount of the displaced element in the soil solution, possibly followed by increased leaching of that element. The long term effect could be a depletion of the displaced element. While it does not seem likely that high rates of applied SO_4-S would have a significant effect on P movement in the soil, the reverse seems possible in some sandy soil. No field work was found to confirm or refute this possible P-S “competition”.

6. **Zinc (Zn):** Phosphorus/Zn interactions have been studied and widely publicized for many years. The results have shown that high levels of either element can depress the uptake of the other. While we know that the interaction can occur, we do not know enough to accurately predict when problem will occur. However, when soil P tests are above about 100 to 150 lb. /acre by either the Bray-P1 or Mehlich 3 procedures, the possibility of depressed Zn uptake should be a concern. Work showing that high Zn rates will depress P uptake indicate that this only happens at impractical and prohibitively high Zn application rates.

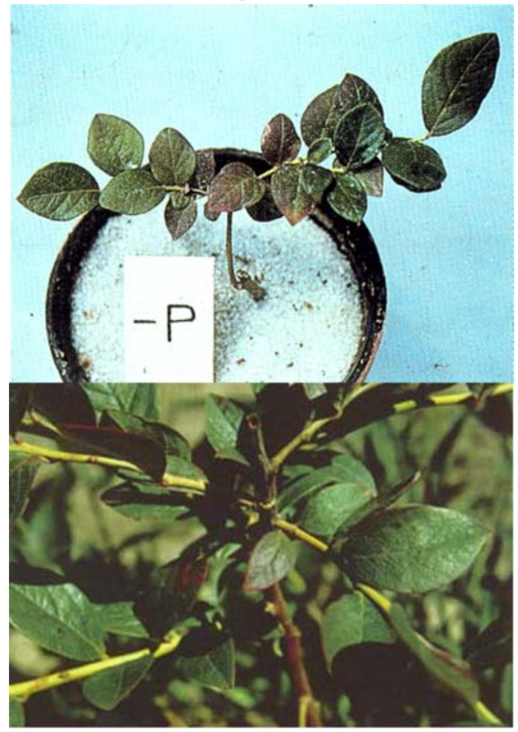
7. **Copper (Cu):** High soil P levels can depress Cu uptake, especially when other Cu limiting conditions are present. As early as the 1940’s it was found that high P applications alleviated Cu toxicity by reducing the availability of soil Cu in Florida citrus groves.

8. **Boron (B):** There has been little research into the possible interactions between B and P. However, boron is an anion in the available form. As such, it reacts with Al and Fe oxides. Since this process is similar to that of soluble P, it seems reasonable that it may interact with P in much the same way as SO_4-S. In the late 50’s and early 60’s, researchers in California reported that applications of $Ca(H_2PO_4)_2$ resulted in lower availability of B, especially in acid soils. Since there is much less available B than P in most soils, we would expect that any interaction would be to limit B availability, not P.

9. **Molybdenum (Mo):** While the interaction between Mo and P has not been studied extensively, some rather convincing evidence indicates that P increases the short term uptake of Mo. In its available form, Mo is an anion. It is presumed that the reason for P increasing the uptake of Mo is similar to the same relationship of P with B and SO_4-S. In all of these cases, both elements react with Al and Fe oxides. A comprehensive report by Stout et al (1951), found that P applications without SO_4-S increased Mo uptake up to 10-fold. The beneficial effects of P on Mo uptake appeared to be stronger in acid soils. That study found that the same P applications plus SO_4-S reduced Mo uptake. Since SO_4-S is an anion, it can compete with Mo for the few anion-adsorption

sites in the soil. Therefore, it appears that while P can increase the short-term uptake of Mo, this may be offset by any significant amount of associated SO_4-S that may be present.

10. **Silicon (Si):** Silicon is not a plant nutrient and is not recommended for application to crops at this time. However, there is considerable evidence with rice and sugarcane indicating that added Si increases water-soluble and easily extractable P. Other results suggest that Si does not increase P uptake, but increases the efficiency of P use within the crop. While there is little practical application for this information for most crops, Si has been shown to improve yields of rice and sugarcane. Silicon has also been shown to be effective as a disease preventative measure in rice.
11. **Arsenic (As):** High levels of As in the soil, as might be found in old orchard soils, can seriously inhibit both Phosphorus and Zinc uptake. However, since soil P is often high and Zn may not be, the effect may be more commonly seen as decreased Zn uptake.



P Deficient Blueberries

Phosphorus Deficiency Symptoms

Visual symptoms of P deficiency are not commonly seen in blueberries. However, blueberries may suffer from P shortages that can only be identified with tissue analysis. This "hidden hunger" for P can offer opportunities to improve crop yields and quality. Visual symptoms of P deficiency include...

1. Overall stunted bushes with small leaves
2. P deficiency typically causes abnormally dark green to blue-green leaves. They may have a purple tint to the green color. The purple tint is often more common on the leaf tips and the leaf edges. The leaves are likely to have a "dull" appearance.
3. Leaf angles relative to the stem may be more narrow than normal (not as close to 90 degrees).
4. Twigs tend to be smaller in diameter and may also have a red-purple tint

Balances and Ratios

While many people believe or suspect that there are desirable ratios of P and K in the soil or a fertilizer program, research has not demonstrated that such ratios exist. It has been shown that in a few crops, there may be a desirable ratio of P with certain other elements like Zn or Ca. However, these relationships rarely play a role in modifying a fertilizer program. For now, we find the best method to evaluate P is the sufficiency range approach to both soil and plant analysis.

Phosphorus Toxicity/Excess

Like N, excess P is not normally considered to have a direct toxic effect. However, directly toxic P reactions have been induced in other crops. Most growers, however, will never experience P toxicity. Typical results of excess P will likely be induced deficiencies of other nutrients. Induced shortages would most likely occur with zinc (Zn), copper (Cu), or iron (Fe).

Using P_2O_5 in a Fertility Program

As with most nutrients, a sound fertilizer program begins with a current soil test. The correct P_2O_5 rate depends on the soil P test and other factors. While blueberries do not remove a lot of P from the soil, the very acid soil pH that they require reduces soil P availability. For that reason, Spectrum Analytic's suggested optimal (Good) soil P test are higher for blueberries than you might expect at first. The following table titled Soil P Status lists Spectrum's evaluation of selected soil P test situations. Where the soil P test is less than optimal, a large part of the recommendation is intended to overcome the natural "P fixation" that occurs in these acid soils. This is the reason that a fertilizer P_2O_5 recommendation may be significantly higher than expected crop removal in some fields.

Soil P Status								
CEC	**0.1**	**5**	**10**	**15**	**20**	**25**	**30**	**35+**
PHOSPHORUS (lb./acre): soil target pH <6.0								
Low	70	60	54	50	47	44	43	40
Medium	140	120	109	102	95	89	83	80
Good	210	180	169	159	153	148	144	140
High	280	240	229	216	211	207	205	200
V High	400	340	316	293	281	274	270	260

Soil P_2O_5 Recommendations				
	Yield Goal (cwt/a)			
	20	**40**	**60**	**80+**
Soil P Status	***lb P_2O_5/acre***			
Low	150	162	166	171
Med	75	89	93	98
Good	5	10	15	20
High	0	0	0	0
V High	0	0	0	0

Potassium (K, K_2O)

Functions of K in the Plant

Potassium does not form a structural part of any plant component or compound. It is required for various metabolic activities and physiological functions. They include the following.

1. Photosynthesis and plant food formation.
2. Sugar and carbohydrate production, transport, and storage.
3. Important, in conjunction with Ca and B, in the proper development of cell walls.
4. Controls plant cell turgor and through this the opening and closing of leaf stoma. This in turn controls the plants ability to effectively respond to drought stress.
5. Potassium affects various quality factors of fruit and vegetables, such as taste and color. Regardless of the nature of the taste or color of fruits or vegetables, a shortage of K may tend to reduce the intensity or "typiness" of that crops taste or color.
6. Improves a plants ability to combat disease, and to a lesser extent insect and nematode damage. Various authorities, reviewing the interaction of K nutrition and plant pests across a wide variety of crop species found the following benefits of proper K nutrition.

PATHOGEN PRESENT	YIELD/GROWTH INCREASE FROM K
Fungus	48%
Bacteria	70%
Virus	99%
Nematodes	115%
Insects, Mites	14%

Factors Affecting K Availability

1. **Soil CEC:** Plant-available soil K is a cation (positive electrical charge represented as K^+). Cations are attracted to, and held by negatively charged colloids (primarily clay and organic matter) that make up the cation exchange capacity (CEC) of the soil. At higher soil CEC values, the soil can and needs to hold more K to adequately feed plants.

2. **Soil test K:** Higher soil test K increases the available K by increasing the amount and balance of K relative to the soil CEC and other cations.

3. **Cation Balance**: Where there is a significant imbalance between available K and the other major cations (Primarily Calcium, Magnesium, and sometimes Hydrogen, Aluminum, or Sodium), it may affect the availability of K to the crop. While blueberry soils are typically low in soluble Ca, Mg, and Na, they may be high in soluble aluminum (Al^{+++}) and hydrogen (H+). The cation competition from both Al and H can reduce the availability of K and other cations.

4. **Soil Moisture:** Soil water is the vehicle required for the transport of K to the roots as well as the absorption of K into the roots. Therefore a water deficiency results in less K uptake.

5. **Soil pH:** As the soil pH is reduced (increasing soil acidity) the availability of K is often reduced (see cation balance).

6. **Soil Temperature:** Cold soils often reduce the availability of K.

7. **Soil compaction:** Compacted soils often reduce the availability of K.

8. **Soil Drainage/Aeration:** As soil drainage is improved, K uptake typically improves.

9. **Soil Salinity:** Saline soils often have excess sodium (Na). One of the negative effects of excess Na is that it reduces the availability of K.

Interactions

1. **K/Mg ratio:** Either K or Mg can reduce the uptake of the other when the "normal" soil balance does not exist. Typically, we find high K levels inhibiting the uptake of Mg. However, some Midwest soils have enough Mg to reduce K availability, especially to high-demand crops. The same relationship can occur with Ca, but seems to be less common.

2. **Other Cation ratios:** There are occasions when K uptake might be restricted due to an imbalance with other cation elements in the soil. For example, in strongly acid soils, required by blueberries, there normally is an excess of soluble hydrogen (H), aluminum (Al), iron (Fe), and possibly other cation elements. These excess elements can compete with K for entry into the plant, and/or set up soil conditions that are unfavorable to efficient K utilization.

3. **Soil pH:** This subject is intertwined with both of the previous points. While we don't think of K as leachable, in acid soils with low CEC's (typical of blueberry soils) K can be more mobile in the soil. Where initial soil tests or fertilizer programs are not sufficient to offset this loss mechanism, we can see lower yields and crop quality due to K stress.

Balances and Ratios

For many years, there have been a few people who claim that there is an "Ideal" ratio of the three principal soil cation nutrients (K, Ca, and Mg). This concept probably originated from New Jersey work by Bear in 1945. This work was related to agronomic crops such as corn and alfalfa, not acid-loving crops like blueberries. Bear suggested that an "ideal" soil would have the following saturations of exchangeable cations… 65% Ca, 10% Mg, 5% K, and 20% H. The cation ratios resulting from these idealizes concentrations are a Ca:Mg of 6.5:1, Ca:K of 13:1, and Mg:K of 2:1. While these ratios would be excellent for most plants that require a soil pH in the mid-six's, they are not relevant to blueberries, and not even required by the other crops.

It is generally accepted that there are some preferred general relationships and balances between soil nutrients. There is also a significant amount of work indicating that excesses and shortages of some nutrients will affect the uptake of other nutrients. However, no reliable research has indicated that there is any particular soil ratio of K, Ca, and Mg that is uniquely superior to another ratio.

Over many years of analyzing and evaluating blueberry plant samples, the most common "balance" problem involving K is when a significant amount of soil or fertilizer K reduces the uptake of a pre-existing low Mg condition.

Potassium Deficiency Symptoms

Visual symptoms of K shortage in blueberries are similar to other crops. Keep in mind that visual symptoms appear only after a severe deficiency. Yield or quality losses typically occur before visual symptoms are noticeable.

1. Marginal scorching of leaves; appearing first and most dramatically in the older leaves. As seen in the pictures, the symptoms may be more extensive by the time they are first discovered.
2. Leaf cupping and curling, sometimes with dead spots
3. Dieback of the tips and shoots
4. Less frequently, younger leaves may develop interveinal chlorosis similar to iron (Fe) deficiency.

K Deficient Blueberries

Some of the most common symptoms of K shortage do not appear as visual leaf symptoms. Since K plays such a large role in disease resistance and the plants ability to control internal water balance, the most common symptoms of K shortage could be an increased occurrence of diseases and increased damage from drought stress.

Potassium Toxicity

Direct K toxicity is very rate. When it occurs, it is likely to show as typical salt damage and is likely to be the result of the combined effect of all salts in the soil. Commonly, in this situation the soil will also be high in sodium (Na) and growers should take appropriate actions to correct the total soluble salt problem in that soil. Actually, a soil with excess total soluble salts is just as likely to cause K deficiency as for K to be a part of excess salt damage. Excessive amounts of K will more commonly be seen as a deficiency of another cation nutrient, particularly magnesium (Mg).

Using K in a Fertility Program

Definitions of soil K status and the resulting recommendations are shown in the accompanying tables. Notice that as the soil cation exchange capacity (CEC) increases, more soil K is required to be identified as “Good”.

Soil K Status Tables								
CEC	**0.1**	**5**	**10**	**15**	**20**	**25**	**30**	**35+**
POTASSIUM (lb./acre)								
Low	90	90	120	150	165	180	200	225
Medium	180	180	240	300	340	380	400	452
Good	270	270	380	460	530	570	615	660
High	400	400	545	690	777	864	930	978
V High	401+	401+	546+	691+	778+	865+	961+	979+

Soil Applied K_2O Recommendations				
	Yield Goal (cwt/a)			
	20	**40**	**60**	**80+**
Soil K Status	***lb K_2O/acre***			
Low	111	132	153	175
Med	86	107	128	150
Good	22	43	64	86
High	0	0	0	0
V High	0	0	0	0

Spectrum Analytic recommendations are designed to increase low soil K tests into the Good range if followed for 3 to 5 years. The precise amount of time that is required to build a soil K test is different for each soil and situation, so we cannot be more accurate than this.

Potassium Sources

Since blueberries do not tolerate chlorides well, and do not use nitrates efficiently, blueberry producers have fewer options than most other crop producers. Potassium chloride is a common material used in many blended fertilizers and should be avoided in fertilizing blueberries.

Product	Typical K2O Analysis	Chemical Formula
Potassium Sulfate	50-54%	K_2SO_4
Sulfate of Potash Magnesia (K-mag/Sul-Po-Mag)	11%	$K_2SO_4 \bullet 2MgSO_4$
Potassium Carbonate	34-48	K_2CO_3
Potassium Metaphosphate	39	KPO_3

Most growers find that only potassium sulfate and sulfate of potash magnesia are widely available and cost effective sources of potassium.

Calcium (Ca^{++})

While you might assume that blueberries should suffer more from Ca deficiency problems than other crops, due to the acid soils, our plant analysis survey suggest that this is not the case. The leaf analysis survey presented earlier showed that only about 9% of the samples were low in Ca. This could be because growers are more aware of the possibilities of Ca shortages in acid soils and are taking actions to prevent it. Many blueberries are grown on low CEC soils which by nature will have a low Ca content. In these situations, Ca uptake can be a problem and Ca fertilization may be needed.

Function

Calcium is essential for many plant functions. Some of them are…

1. Proper cell division and elongation
2. Proper cell wall development
3. Nitrate uptake and metabolism
4. Enzyme activity
5. Starch metabolism
6. Low Ca content of many fruit crops often contributes to poor fruit storage quality

Calcium is transported in the xylem via an ion exchange mechanism. It attaches to lignin molecules and exchange must occur with calcium or another similar cation (e.g. Mg^{++}, Na^{+}, K^{+}, NH_4^{+}, etc.). Calcium is not very mobile in the soil, or in plant tissue, therefore a continuous supply is essential.

Factors Affecting Ca Availability

Calcium is found in many of the primary or secondary minerals in the soil. In this state it is relatively insoluble. Calcium is not considered a leachable nutrient. However, over many years, it will move deeper into the soil. Because of this, the sub-soil is likely to have higher levels of Ca, and a higher pH.

1. **Soil pH:** Acid soils have less Ca, and high pH soils normally have more.
2. **Soil CEC:** Lower CEC soils hold less Ca, and high CEC soils hold more.
3. **Cation competition:** Abnormally high levels, or application rates of other cations, in the presence of low to moderate soil Ca levels tends to reduce the uptake of Ca.
4. **Alkaline sodic soil (high sodium content):** Hopefully, this is not applicable to anybody's planned blueberry land, because this type of soil will normally be very high pH. Excess sodium (Na) in the soil competes with Ca, and other cations to reduce their availability to crops.
5. **Sub-soil or parent material:** Soils derived from limestone, marl, or other high Ca minerals will tend to have high Ca levels as well as high soil pH. Soils derived from shale or sandstone will tend to have lower levels.

Interactions

1. **Other cations:** Being a major cation, Ca availability is related to the soil CEC, and it is in competition with other major cations such as sodium (Na^{+}), potassium (K^{+}), magnesium (Mg^{++}), ammonium (NH_4^{+}), iron (Fe^{++}), and aluminum (Al^{+++}) for uptake by the crop. High K applications have been known to reduce the Ca uptake in apples, which are very susceptible to poor Ca uptake and translocation within the tree. In the acid soils that blueberries require, the major cation interferences with Ca are likely to be Al, Fe, or K.
2. **Sodium (Na^{+}):** . High Na soils typically have a much higher pH than blueberries can tolerate. High levels of soil Na will displace Ca and lead to Ca leaching. This can result in poor soil structure and possible Na toxicity to the crop. Conversely, applications of soluble Ca, typically as gypsum, are commonly used to desalinate sodic soils through the displacement principle in reverse

3. **Phosphorus (P):** This interaction is not applicable to blueberries if the soil pH is in the correct acid range. It is listed here only because it is commonly found in agricultural articles. As the soil pH is increased above pH 7.0, free or un-combined Ca begins to accumulate in the soil. This Ca is available to interact with other nutrients. Soluble P is an anion, meaning it has a negative charge. Any free Ca reacts with P to form insoluble (or very slowly soluble) Ca-P compounds that are not readily available to plants. Since there is typically much more available Ca in the soil than P. This interaction nearly always results in less P availability.
4. **Boron (B^-):** High soil or plant Calcium levels can inhibit B uptake and utilization in some crops. We assume that the effect would be similar in blueberries, although it has not been demonstrated with blueberries. While this effect is not normally large, it has been reported that Ca sprays and soil Ca applications have occasionally been used to partially detoxify B caused by excessive applications.

Balances and Ratios

The following information does not refer directly to blueberries, but it is generally applicable to all crops. It is included here because there are often questions about the soil Ca:Mg balance related to a wide variety of crops. Of course, the very acid soils required for blueberries typically means low soil levels of both Ca and Mg. It has been our experience that where either nutrient is needed, it is because of the low soil level, not a question of the balance between Ca and Mg. In any event, the following information was assembled to inform all crop producers about this question.

For many years, there have been a few people who claim that there is an “Ideal” ratio of the three principal soil cation nutrients (K, Ca, and Mg). Most of the time this concept is applied to more “typical” crops like corn and soybeans, rather than blueberries. However, the principles of the arguments for and against a single desirable cation balance or ratio in the soil should be applicable to blueberries as well.

The cation balance/ratio concept probably originated from New Jersey work by Bear in 1945 that projected an ideal soil as one that had the following saturations of exchangeable cations… 65% Ca, 10% Mg, 5% K, and 20% H. The cation ratios resulting from these idealizes concentrations are a Ca:Mg of 6.5:1, Ca:K of 13:1, and Mg:K of 2:1.

It is generally accepted that 1) there is a competitive relationship between K, Ca, and Mg and 2) in very general terms, there should be a minimum threshold for the soil content and/or percent saturation for each nutrient in the soil. These two requirements naturally result in some very broad balances and ratios of these nutrients in the soil. However, no reliable research has indicated that there is any specific ratio or balance of these nutrients in the soil that is superior to others.

Over the years, a significant amount of conversation and salesmanship has revolved around the concept of the ideal soil Ca:Mg ratio. Most of the claims for the ideal ratio range between 5:1 and 8:1.

Some of the claims are that the correct soil Ca:Mg ratio will…

1. Improve soil structure.
2. Reduce weed populations, especially foxtail and quackgrass, plus improve forage quality.
3. Reduce leaching of other plant nutrients.
4. Generally improve the balance of most soil nutrients.

According to Dr. Stanley Barber, Purdue Univ., **“There is no research justification for the added expense of obtaining a definite Ca:Mg ratio in the soil…Research indicates that plant yield or quality is not appreciably affected over a wide range of Ca:Mg ratios in the soil.”**

Wisconsin research found that yields of corn and alfalfa were not significantly affected by Ca:Mg ratios ranging from 2.28:1 to 8.44:1…in all cases, when neither nutrient was deficient, the crops internal Ca:Mg ratio was maintained within a relatively narrow range consistent with the needs of the plant. These findings are supported by most other authorities. A soil with the previously listed ratios would most likely be fertile. However, this does not mean that a fertile soil requires these *specific* values (or any other). Adequate crop nutrition is dependent on many factors other than a specific ratio of nutrients. **It will rarely be profitable to spend significant amounts of fertilizer dollars to achieve a specific soil nutrient ratio.**

In later sections of this paper, you will find references to nutrient ratios. However, in most cases there will not be specific numerical ratios associated with these relationships. The intention is to indicate that as the relative abundance of the nutrients changes significantly, it could affect the availability of the other nutrient. This concept is much less specific than claiming that there is a value to a specific numerical ratio.

Deficiency Symptoms

Visual symptoms of Ca deficiency are rarely seen in blueberries. Experimentally induced Ca deficiency symptoms included interveinal chlorosis of younger leaves and scorching of the margins of older leaves. In other crops, extreme deficiencies have included deformed growing points in many different crops.

Ca Deficient Blueberry

Toxicity

Calcium, for all practical purposes, is not considered to have a directly toxic effect on plants. Most of the problems caused by excess soil Ca are the result of the typically high soil pH effects that is coincidental with high soil Ca levels much of the time. Another problem from excess Ca may be the reduced uptake of other nutrients, possibly leading to deficiencies of nutrients, such as potassium, magnesium, phosphorus, boron, copper, iron, or zinc. Induced deficiencies caused by excess Ca are rare, except perhaps when accompanied by high soil pH.

Using Calcium in a Fertility Program

As with other nutrients, Ca should be applied based on a soil test. The definitions of soil Ca status levels used by Spectrum Analytic is shown in the following table.

Spectrum makes calcium recommendations in terms of elemental Ca, as we do for other nutrients. Since lime is rarely needed on blueberries, producers should use other Ca sources. Calcium sources that are pH neutral, such as gypsum ($CaSO_4$) or other fertilizer products are available. Gypsum can also be used to correct high salt conditions in the soil.

Soil Ca Status								
CEC-->	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**
Soil Status	***Soil Ca (lb./acre)***							
Low	300	400	1000	1500	2000	2500	3000	3500
Medium	700	800	2000	3000	4000	5000	6000	7000
Good	1250	1600	2800	4200	5600	7000	8500	9900
High	1600	1800	3600	5400	7200	9000	10800	12600
V High	1601+	1801+	3601+	5401+	7201+	9001+	10801+	12601+

Recommended rates of Calcium: (follow soil test or plant analysis recommendations)

Spectrum Ca recommendations in the accompanying table are intended for soil broadcast application. They are intended to feed the crop, rather than to correct the soil Ca in a single application. As such, they are not likely to correct a poor soil Ca level in the near term.

Soil Applied Calcium Recommendation Table										
CEC ---->	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
Soil Status	***lb Ca/acre***									
Low	50	70	90	110	130	150	170	190	210	230
Med	35	35	50	65	80	95	110	110	110	110
Good	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0
V High	0	0	0	0	0	0	0	0	0	0

North Carolina State University has published a formula for calculating the amount of gypsum required to correct the soil Ca level (see following section). We have no other verified formula for generating a Ca recommendation to increase the soil Ca level to a specific target level. The N. Carolina formula might not be accurate for your situation, so it might be wise to make multiple smaller applications so you can monitor and adjust to the actual soil test buildup rate. The N. Carolina formula is as follows.

Lb. gypsum/acre = C.E.C. x (desired %Ca sat. - present %Ca sat) x 18

Other Calcium Fertilizer Sources

This table was published for apple growers. As such, it contained calcium chloride and calcium nitrate listings, which have been omitted for this paper. **Be sure to find out if any of the listed products and rates of application are confirmed as being suitable for use on blueberries before making any applications.** Spectrum Analytic has not independently confirmed the accuracy or inclusiveness of the data contained in this table.

Calcium materials for uses on apple, with labeled rates per acre per application, per acre per season, and per acre per year (2004-2005 Pennsylvania Tree Fruit Production Guide)

Product Name	% Ca	Lb/Gal	Manufacturer	Product/A/spray min.-max.	No. of Apps.	Total prod/A/season Min.-max.	Total lb Ca/A/season Min.-max.
CaB	6.0	10.0	Stoller, Inc. (1-800-258-8688)	3-6 pt.	8	3-6 gal	1.8-3.6
CaB'y	10.0	11.9	Stoller, Inc. (1-800-258-8688)	2-4 qt	8	4-8 gal	4.8-9.5
Cor-Clear Dry	34.5	Beads	SEGO Intl., (503-796-0133)	4-8 lb	4-6	16-481b	5.5-16.3
Folical	10.0	9.6	Agrimar Corp. (1-800-284-9898)	1 gal	6-8	6-8 gal	5.8-7.7
Fung-Aid	10.0	11.9	Stoller, Inc. (1-800-255-9548)	2-4 qt	8-15	15.5-8.2 gal	6.5-9.7
Link-Calcium 6%	6.0	10.3	Wilbur-Ellis Co. (1-800-553-2333)	2-4 qt	4	2-4 gal	1.2-2.5
Nutri-Cal 7%	8.0	11.1	CSI Chemical Corp. (1-800-247-2480)	1-2 qt	3-8	.75-4.0 gal	.67-3.6
Nutra-Phos 12	11.0	Powder	Pace Intl. LP (1800-936-6750)	3-101b	4-8	12-801b	2.3-8.8
Nutra-Phos 24	20.0	Powder	Pace Intl. LP (1-800-936-6750)	3-101b	4-8	12-801b	2.4-16.0
Nutra-Phos	28.0	Powder	Pace Intl. LP (1-800-936-6750)	3-101b	4-8	12-801b	3.4-22.4
Nutra-Plus	6.0	10.0	Custom Chemicides (209-264-0441)	1-3 qt	8-11	2-8.2 gal	1.2-4.9
Sett	8.0	11.4	Stoller, Inc. (1-800-255-9548)	1 gal	8-11	8-11 gal	7.3-10.0
Sorba-Spray Ca	8.0	10.8	Pace Intl. LP (1800-936-6750)	1-4 qt.	4-6	1-6 gal	0.9-5.2
Sorba Spray CaB	5.0	10.0	Pace Intl. LP (1800-936-6750)	1-4 qt	4-6	1-6 gal	0.5-3.0
Stopit Calcium	12.0	10.8	Pace Intl. LP (1800-936-6750)	1 gal	6-8	6-8 gal	7.8-10.4
Tracite Calcium 6%	6.0	10.0	Helena Chem. Co. (901-748-3200)	3-6 pt	8	3-6 gal	1.8-3.5
Traco Pit-Cal	12.0	11.7	Traylor Chem. Co. (1-800-348-3361)	0.5-2 gal	7	3.5-14 gal	4.9-19.[6]
Wuxal Calcium	10.7	13.3	AGLUKON Div. (1-800-832-8788)	3-4 pt	5	1.9-2.5 gal	2.7-3.6

Taken from Vermont Apple Newsletter, 6-16-2004, which attributed data to Pennsylvania Tree fruit Production Guide, 2004-2005.

Magnesium (Mg^{++})

Magnesium in the Soil

Like Ca, our plant analysis survey did not show Mg to be a problem in most samples. However, Mg is typically low in acid, low CEC soils and many of our customers may already be preventing this problem with Mg applications.

Magnesium is a component of several primary and secondary minerals in the soil, which are essentially insoluble, for agricultural considerations. These materials are the original sources of the soluble or available forms of Mg. Magnesium is also present in relatively soluble forms, and is found in ionic form (Mg^{++}) adhered to the soil colloidal complex. The ionic form is considered to be available to crops.

Function

Magnesium is essential for many plant functions. Some of them are…

1. Photosynthesis: Mg is the central element of the chlorophyll molecule.
2. Carrier of Phosphorus in the plant
3. Magnesium is both an enzyme activator and a constituent of many enzymes
4. Sugar synthesis
5. Starch translocation
6. Plant oil and fat formation
7. Nutrient uptake control
8. Increase Iron utilization
9. Aid nitrogen fixation in legume nodules

Factors Affecting Availability

1. **Soil Mg content:** Soils inherently low or high in Mg containing minerals

2. **Soil pH:** Acid soils are normally low in Mg and low soil pH decreases Mg availability.

3. **Soil Mg:Mn ratio:** High available Mn can directly reduce Mg uptake. This may be independent of the acid conditions normally associated with excess available Mn in the soil.

4. **Soil CEC:** Low CEC soils hold less Mg, while high CEC soils can hold abundant Mg. However, if a high CEC soil does not happen to have strong levels of Mg, it will tend to release less of the Mg that it holds.

5. **Cation competition:** Soil with high levels of K or Ca will typically provide less Mg to the crop

6. **High cation applications:** High application rates of other cations, especially K, can reduce the uptake of Mg.

7. **Low soil temperatures:** Cold soils typically inhibit the uptake of most nutrients.

Interactions

1. **Other cations:** Being a major cation, Mg availability is related to the soil CEC, and it is in competition with other major cations such as calcium (Ca^{++}), potassium (K^{+}), sodium (Na^{+}), ammonium (NH_4^{+}), iron (Fe^{++}), and aluminum (Al^{+++}). It appears that potassium is a stronger competitor with Mg than is often mentioned. We have frequently seen that whenever the soil K level is higher than desired, or when the soil K:Mg ratio (in lb./acre) is above 1.5:1 (or the soil Mg:K ratio is less than 0.67), plant Mg levels are reduced. It may seem inconsistent to list a specific numerical K:Mg ratio, when we earlier stated that specific numerical ratios are not valid. However, we are simply stating that Mg problems are more frequent or severe when the soil K:Mg ratio exceeds 1.5. We are not claiming that there is an ideal K:Mg ratio.

2. **Phosphorus:** In the soil, P uptake is often enhanced when applied with Mg fertilizers. However, mixing some liquid or suspension sources of P and Mg fertilizers can lead to a reaction can result in the formation of a large amount of precipitated material, to the point of near solidification of the mixture.

3. **Sulfur:** Sulfur leaching is often increased where supplemental Magnesium is applied

Mg Deficient Blueberry

Balances and Ratios (see section on Ca)

Deficiency Symptoms

The classic deficiency symptom is interveinal chlorosis of the lower/older leaves. However, blueberries, like some other crops will often have a reddening of the affected leaves. The first stage of visual symptoms is generally a more pale green color that may be more pronounced in the lower or older leaves.

Toxicity

Magnesium toxicity is rare. Crops grown on heavy montmorillonite clay soils which have been poorly fertilized with potassium may exhibit excesses of Magnesium in their tissue. But, before the tissue level approaches toxicity, Potassium deficiency will occur. Higher tissue levels of Magnesium are usually found in the older leaves on the plant and may be associated with diseased or damaged leaves.

Using Magnesium in a Fertility Program

Soil testing is the first step in determining a need. At Spectrum Analytic we evaluate soil Mg levels as shown in the following table. As always Plant Analysis is the only effective method of identifying "hidden" Mg shortages

Soil Status Tables								
CEC	**0.1**	**5**	**10**	**15**	**20**	**25**	**30**	**35+**
	Mg (lb./acre)							
Low	90	90	120	151	163	180	202	227
Medium	180	180	240	299	341	378	403	454
Good	270	270	480	720	912	1080	1224	1344
High	400	400	600	900	1152	1380	1584	1764
V High	401+	401+	601+	901+	1153+	1381+	1585+	1765+

Magnesium fertilizer recommendations are controlled by data such as illustrated in the following table. The recommendations are in terms of elemental Mg per acre, applied as a broadcast application. We will also recommend dolomitic (high Mg) lime when lime is needed. We realize that Mg fertilizer is often applied in bands of various widths and placement. In these situations, the rate of Mg can normally be reduced. However, since the types and placement of bands or other concentrated applications can vary considerably, we are not able to be more specific.

Magnesium Recommendation Table (broadcast rates, reduce for band applications)						
Crop Response	**Low**		**Medium**		**High**	
Soil K:Mg Ratio	**0-1.5**	**1.51+**	**0-1.5**	**1.51+**	**0-1.5**	**1.51+**
Soil Mg Status	***lb Mg/acre***					
Low	50	70	60	80	70	90
Med	25	35	30	40	35	45
Good	0	20	0	20	0	20
High	0	20	0	20	0	20
V High	0	0	0	0	0	0

Magnesium is a constituent of most agricultural lime, as well as specific Mg fertilizers. While lime is rarely needed on blueberries, where it and Mg are both needed, dolomitic lime is normally the most cost-effective source of Mg, as well as the most efficient method of increasing the soil Mg level. Remember that agricultural lime is not very soluble, so in the first year of Mg fertilization, the crop may benefit from Mg fertilizer in addition to dolomitic lime. In later seasons, the earlier application of dolomitic lime may well be sufficient for several years. As with most micronutrients, row applied Mg (fertilizer, not lime) is nearly always more effective than broadcast application of similar rates.

If band-applied Mg is planned, it may be beneficial to minimize or eliminate band-applied K in order to reduce K/Mg competition. However, materials such as K-Mag or Sul-Po-Mag that contain both nutrients have been used successfully with other crops to partially satisfy Mg needs on soils where the crops had significant Mg stress. This has been seen, even where the Mg stress is caused by excessively high soil K levels. Likewise, broadcast recommendations of K_2O equal to, or in excess of 400 lb/A (not likely with blueberries) should be split into two or more applications. Good responses have been obtained from foliar applications of both Epsom salts ($MgSO_4$) and Magnesium chelates. Also remember, foliar applications are only supplements to a sound soil fertility plan. You should not expect foliar programs to replace a sound soil fertility program.

Magnesium Fertilizers

The following list does not include all proprietary Mg fertilizers that are currently on the market and we are not able to provide a current list of suppliers. You should contact fertilizer suppliers, appropriate publications, and possibly internet sources for Mg fertilizer suppliers.

Product	Typical Mg Analysis	Chemical Formula
Dolomitic limestone	5-12%	$CaMg(CO_3)2$
Magnesium sulfate (epsom Salts)	10%	$MgSO_4$•$7H_2O$
Sulfate of Potash Magnesia (K-mag/Sul-Po-Mag)	11%	K_2SO_4•$2MgSO_4$
Magnesium oxide	45-60%	MgO
Magnesium oxysulfate	variable based on sulfate and oxide concentrations	MgO + $MgSO_4$
Magnesium chelates	Typically 15-58%	varied
Non-chelated proprietary products	variable, up to 20%	chlorides, sulfates, others

Sulfur (S)

As our plant sample survey indicates, S shortages are not normally a problem for blueberries. This is likely because so many of the fertilizer sources that are most appropriate for blueberries contain significant amounts of sulfur. However, if your blueberries require additional sulfur, the following information may be helpful.

Sulfur in the Soil

Most soil sources of S are in the organic matter and are therefore concentrated in the topsoil or plow layer. Elemental S, as found in soil organic matter and some fertilizers, is not available to crops. It must be converted to the sulfate (SO_4^{--}) form to become available to the crop. This conversion is performed by soil microbes and therefore requires soil conditions that are warm, moist, and well drained to progress rapidly. The sulfate form of S is an anion (negative charge), and therefore is leachable. As a rough rule-of-thumb, it can be considered to leach through the soil profile at about 50% of the rate of nitrates (NO_3^-). In soils with a significant and restrictive clay layer in the sub-soil, it is not uncommon to find that sulfate has leached deeper into the soil over time and become "perched" on the clay layer. This $SO_4^{--\ is}$ available to crops if-and-when the roots reach this area of the soil.

Function

Sulfur is essential for many plant functions. Some of them are…

1. A structural component of protein and peptides
2. Active in the conversion of inorganic N into protein
3. A catalyst in chlorophyll production
4. Promotes nodule formation in legumes
5. A structural component of various enzymes
6. A structural component of the compounds that give the characteristic odors and flavors to mustard, onion and garlic

Factors Affecting S Availability

1. **SAND:** Sulfur is leachable, plus sandy soils are typically low in OM, therefore these soils are often low in sulfur.
2. **SOIL OM:** Organic matter is a reservoir for S
3. **COLD SOIL:** The conversion of various forms of S to the available sulfate (SO_4) form is a microbial process; therefore low soil temperatures slow this process.
4. **POOR DRAINAGE:** The conversion of various forms of S to the available sulfate (SO_4) form is a microbial process requiring oxygen; therefore saturated soil slows this process.
5. **POLLUTION:** Industrial atmospheric pollution has been is a significant source of S over the years. Therefore, fields that are downwind from such sources may have higher levels of available S. However, in recent decades, S emissions and less S is coming from this source.
6. **INCIDENTAL OCCURANCE IN OTHER FERTILIZERS:** In the past, many fertilizer products contained significant amounts of S as a by-product or contaminant from the manufacturing process. In today's higher-analysis fertilizers this is not a significant source of S.
7. **IRRIGATION WATER:** Irrigation water may contain high levels of S, and excess irrigation of sands can leach S out of the root zone.
8. **SO_4:NH_4 APPLICATIONS:** Added NH_4 has been shown to appreciably enhance the uptake of SO_4.

Interactions

1. **OTHER ANIONS:** Anions tend to compete with other anions in terms of availability and plant uptake. However, this is not normally a significant problem unless unusually large amounts of one anion are applied. However, in such situations excess sulfate-S (SO_4^{--}) could theoretically reduce the uptake of some anions such as nitrates (NO_3^-), the available forms of molybdenum (MoO_4^-) or boron (BO_3^{-3}). Conversely, excessive amounts of other anion nutrients could equally as well reduce the uptake of sulfate-S. However, since only nitrates might be applied in large amounts and even this is not likely with blueberries, competitive reduction of S uptake is not likely to be a problem.

2. **COPPER:** While rare, S can, in some crops, effectively reduce the possibility of Copper toxicity by creating Cu-S complexes. We don't know of a situation where this has been shown to be significant with blueberries, but the theoretical possibility exists.

Balances and Ratios

Some people will recommend that sulfur be applied in a particular ratio with N. The origin of this concept appears to come from the fact that proteins contain specific ratios of N and S. While it is entirely possible that many crop producers will get a yield response from applying N and S together, this does not prove that a particular N:S ratio from fertilizer is desirable. Using this approach to recommending sulfur applications is not based on sound agronomic principles and data. For example, it completely ignores the S (and N) that is naturally available from the soil. Also, it assumes that both the applied N and S will be taken up in the same ratio that they were applied. If the crop takes up N and S in a particular ratio, the dominant controlling factors will not be the ratio of these elements applied as fertilizer. The very complex soil chemistry, microbiology, as well as variable crop, culture, and environmental factors will inevitably work against the crop absorbing N and S in the same ratio as was applied as fertilizer.

It is true, however, that the N nutrition of a crop affects the S uptake. We routinely receive plant samples that are low in N. It is very common to see that these samples also have an S shortage. In these cases, additional N will normally increase S uptake, while additional S fertilizer rarely corrects the S shortage unless additional N is also applied. In other words, an N shortage will induce an S shortage, even if there is abundant S available to the crop. However, an S shortage (other than a massive deficiency) will not typically induce an N shortage.

Deficiency Symptoms

Sulfur is a necessary constituent in several amino acids and proteins. Since these are building blocks in the plant, Sulfur becomes fixed into the plant's structure. Therefore, the classic symptom of deficiency is a chlorosis of the younger leaves. However, many times most of the foliage has a pale green color, and the difference in "paleness" between the older and younger foliage may not be dramatic. This can lead to a confusion of S-deficiency symptoms with other nutrients. As the accompanying picture illustrates, the veins may be a darker green color, but this is not always as significant as in this photo.

Sulfur Deficient Blueberry

Toxicity

For practical purposes S toxicity doesn't happen. Excessive applications of elemental S most often result in a depression of soil pH and an increase of the problems that occur with the pH decrease. In fact, as the Nutrient Availability chart in the previous section on soil pH illustrates, sulfur availability is actually reduced as the pH of the soil decreases. This problem would not be expected with acid-loving crops like blueberries.

Using Sulfur in a Fertility Program

Plant analysis is the first step in refining a fertilizer program. It is really the only way to confidently identify deficiencies. It can also detect imbalances such as N:S and P:S ratios that may be a problem. Plant analysis is also useful to determine if enough sulfur is being taken up from soils shown to be borderline or low in the soil analysis results. Once identified, correcting S problems is relatively simple with fertilizer applications. The following recommendation ranges are typical for supplying S as a nutrient. These rates will not be nearly high enough to cause soil acidification in any near-term time period. See the previous section on soil pH for approximate rates of S required to acidify soils.

Recommended rates of S (as SO_4-S)

Broadcast:	3 to 15 lb./A
In-row:	1 to 8 lb./A
Foliar:	1.0 to 1.5 lb./A

Many times both a soil and a plant analysis are needed to confirm a sulfur shortage (hidden hunger). However, visible leaf symptoms of S deficiency indicate a severe shortage with a strong probability that the plants have already suffered damage. Also remember that as growers strive for those exceptional yields, the need for S and other nutrients will increase proportionally.

Sulfur Fertilizer Sources

Product	Chemical Formula	Typical Sulfur Content
Ammonium Sulfate	$(NH_4)_2SO_4$	24%
Potassium Sulfate	K_2SO_4	18-19%
Sulfate of potash magnesia (K-Mag/Sul-Po-Mag)	$K_2SO_4 \bullet 2MgSO_4$	22%
Elemental Sulfur	S	90%
Calcium Sulfate	$CaSO_4$	15-22%
Epsom Salts	$MgSO_4 \cdot 7H_2O$	14%
Ammonium ThioSulfate	$NH_4S_2O_3$	26%
Aluminum Sulfate	$Al_2(SO_4)_3$	14.4%
Ferrous Sulfate	$FeSO_4$	12%
Sulfuric Acid	H_2SO_4	32%

Micronutrients

Micronutrients are essential nutrient elements that the plants require in very small amounts. They are every bit as essential as all other nutrients. Only the quantity needed is different. The following elements are classified as micronutrients for all plants

Boron (B)	**Manganese (Mn)**
Copper (Cu)	**Zinc (Zn)**
Iron (Fe)	**Molybdenum (Mo)**

The available literature suggests that the relative responsiveness of blueberries to each of the micronutrients is as follows.

Blueberry Response to Micronutrients

Boron	Copper	Iron	Manganese	Zinc	Molybdenum
Low	**Med.**	**High**	**Low**	**No Data**	**No Data**

We have to be a little bit careful in using this type of very general information. It may mean that blueberries have an unusually high internal demand for the "high response" nutrients. On the other hand, it could mean that under the conditions of crop production, the "high response" nutrient is most often limiting. Our plant analysis survey data, listed earlier, does not completely agree with this information. We found that Cu was most often low in the samples, while Fe was the second most often low nutrient and B was the third most common micronutrient shortage. Manganese and Zn were rarely low. Keep in mind that in our survey, the growers might have already applied various micronutrients, so it isn't necessarily an unbiased survey.

In any event, micronutrients are an important part of any fertilizer program for blueberries or any other crop and growers should understand how to identify and correct these nutrient needs.

Boron (BO_3^{-3})

Boron in the Soil

Total soil boron (B) content can range from around 20 lb./acre to over 200 lb./acre (10-100+ ppm). However, only a tiny fraction of this amount is available to the crop. Plants take up B as the borate anion, BO_3^{-3}. Much of the total soil B is present as a component of Tourmaline, a highly insoluble mineral. Most of the remainder is in secondary, moderately insoluble minerals. The forms of B that make up the soil B reserves which contribute to the plant available, soluble B fraction of the soil include inorganic borate complexes of Ca, Mg, and Na, plus various organic compounds formed from plant and microbe decomposition. Since the available form of B is the borate anion, B is leachable in low CEC soils when excess water moves through the soil. However, B is not as readily leachable as nitrogen.

Functions

Boron is essential for many plant functions. Some of them are…

1. Maintaining a balance between sugar and starch.
2. The translocation of sugar and carbohydrates.
3. It is important in pollination and seed reproduction.
4. It is necessary for normal cell division, nitrogen metabolism, and protein formation.
5. It is essential for proper cell wall formation.
6. It plays an important role in the proper function of cell membranes and the transport of K to guard cells for the proper control of internal water balance.

Factors Affecting Availability

1. **pH:** Much of the literature on micronutrients will state that high pH reduces B availability. However, within the normal soil pH range at which blueberries are grown, soil pH is not a factor in B availability.
2. **Leaching conditions:** B is mobile, so coarse soils and high rainfall may cause temporary soil shortages.
3. **Low OM:** Organic matter is a reservoir for B, and many other nutrients. Therefore, low soil OM is a common cause of low B supply.
4. **Low Moisture:** Boron uptake is in part determined by water uptake rate, therefore drought reduces B uptake. Also, B deficiency reduces root growth, thus further reducing B uptake.
5. **Soil Ca:B Balance:** Some work has indicated that high soil Ca levels, independent of soil pH can reduce B uptake. In most situations however, high soil Ca will be accompanied by higher soil pH, and the pH effect will dominate. In some cases of B toxicity with other crops, applications of a soluble form of Ca have reduced the toxic effects.
6. **K:B Balance:** Work with corn has show that high K rates can sometimes depress yields if B is limiting. We do not know if the same would hold true for blueberries.
7. **Zn:B and P:B Balance:** Work with barley showed that Zn applications can reduce B accumulation. This same work showed that high P applications increased B accumulation. This doesn't mean that the same effects will necessarily be seen in blueberries, but they might be.
8. **N Stress:** Low N availability decreases the vigor of plants to an extent that they may fail to take up adequate amounts of many other nutrients. Boron uptake can be affected in this way.

Blueberry Tip Dieback Due To B Deficiency

Deficiency Symptoms

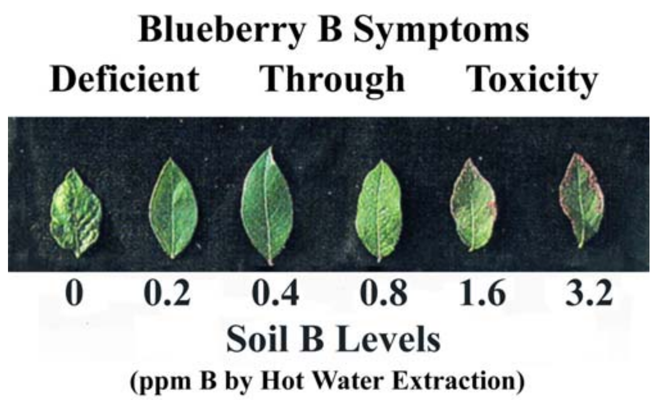
Visible B deficiency symptoms can take two forms. They may appear on the vegetative plant parts or on the flowering/fruiting clusters.

Symptoms on the vegetative plant parts occur on the youngest tissue and include somewhat smaller new leaves that may tend to look "crinkled". However, be careful using this as a guide because mild B toxicity might also look like this. As the deficiency progresses, you may see the dieback of the growing tips of the bushes. This would include the leaves, buds and the youngest stems.

Boron plays a major role in the viability of pollen tubes as they germinate and fertilize the flowers. A boron shortage at pollination can result in a significant lack of berry formation, even if no visible symptoms were seen in the vegetative growth. Symptoms on the flowering and fruiting clusters would most likely show up as poor fruit set. This might take the appearance of clusters that are missing a large number of berries at random throughout the cluster.

Toxicity

The range between a correct application rate and a toxic one is not large, so it is relatively easy to apply too much boron. Because of this, it is very important to get uniform mixing and application, especially when applying in concentrated bands or foliar. Because of the slow transport of B in the plant, symptoms generally appear on the older leaves and consist of margin or leaf tip chlorosis, browning of leaf tips, which is quickly followed by the death of the affected tissue or defoliation. These symptoms can be confused with K deficiency, excess salt damage, or chloride toxicity, so you really cannot depend on visual symptoms for an accurate diagnosis. You need to take leaf samples for proper identification.



Since B is a mobile element in the soil, excess B from over-application can be corrected over time with leaching. Applications of lime and sources of soluble Ca have been shown to be effective in reducing B toxicity, and it has been reported that additional N application can be of benefit.

Using Boron in a Fertility Program

Recommended rates of B are:

Broadcast:	0.5 to 1.0 lb./A
In-row:	Not Recommended
Foliar:	0.10 to 0.25 lb./A

Application methods are probably more important with B than most other nutrients for several reasons.

1. Blueberries need very small amounts, as do most plants
2. Toxicity can occur at low application rates
3. Concentrated applications can greatly increase uptake
4. Boron is mobile in the soil, and broadcasting is effective in supplying the crop.
5. Broadcasting, unlike foliar, requires only one application per season to adequately supply the crop. It is often sufficient to make a single foliar application of B to blueberries and other perennial crops.
6. Blending dry formulations to get a uniform mixture of B throughout the entire load of fertilizer can be difficult. The impregnation of dry fertilizer blends with dissolved Solubor has been successfully used to assure uniform distribution.

For these reasons, broadcasting B containing fertilizers is the preferred application method. If some form of banding is to be used, take the necessary steps to insure proper and proportional application rates plus uniform distribution of B.

Boron Fertilizer Sources

Product	Chemical Formula	Approximate %B
Borax	$Na_2B_4O_7 \cdot 10H_2O$	11%
Boric Acid	H_3BO_3	17%
Sodium tetraborate	$Na_2B_4O_7 \cdot (0\text{-}10)H_2O$	10-20%
Solubor	$Na_2B_{10}O_{16} \cdot 0H_2O$	20%

Copper (Cu^{++})

Function

Copper is essential for many plant functions. Some of them are…

1. It functions as a catalyst in photosynthesis and respiration.
2. It is a constituent of several enzyme systems involved in building and converting amino acids to proteins.
3. Copper is important in carbohydrate and protein metabolism.
4. It is important to the formation of lignin in plant cell walls which contributes to the structural strength of the cells.
5. Copper affects the flavor, the storageability, and the sugar content of fruits.
6. Copper is a natural fungicide that inhibits the infection and growth of fungus pathogens.

Deficiency Symptoms (no photo available)

Young tissues show chlorosis, distortion, and necrosis (death). The death of the growing points often lead to excessive branching. Excessive wilting and reduced disease resistance result from the weak cell walls caused by Cu deficiency. Reduced seed and fruit yield is caused mainly by male sterility. Copper deficiency often causes a complete failure to set flowers. Copper is found to be evenly distributed in the plant, but is relatively immobile. Therefore, a constant supply is needed throughout the growing season.

Factors Affecting Availability

1. **Root Growth:** Copper is the most immobile micronutrient, therefore anything that inhibits new root growth will inhibit Cu uptake.
2. **Soil pH:** Much of the literature on micronutrients will state that high pH reduces Cu availability. However, within the proper acid soil pH range for blueberries, soil pH is not a factor in Cu availability.
3. **Organic Matter:** Copper is readily and tightly complexed by organic matter, therefore high soil organic matter levels reduce Cu availability.
4. **Flooding:** Waterlogged soils can reduce Cu availability while they are saturated; however after they are drained the Cu will become available again.
5. **Cu:Zn Balance:** High Zn levels will reduce Cu availability.
6. **Cu:N Balance:** High N uptake in the presence of marginal Cu levels can lead to a reduction of Cu transport into the growing tips of plants.
7. **Cu:P Balance:** High soil and plant P levels can reduce Cu uptake due, at least in part, to reduced soil exploration by mycorrhizas associated with plant roots. There is not a specific soil P level at which this occurs under all conditions.
8. **N Stress:** Low N availability decreases the vigor of plants to an extent that it may fail to take up adequate amounts of many other nutrients. Copper uptake can be affected in this way.

Toxicity

Copper should not be applied to soils without a demonstrated need through soil and plant analysis. Toxic effects from over-application can last many years. Symptoms appear in young tissue and include; dark green leaves followed by induced Fe chlorosis in which the leaves may appear nearly white. Plants may also have thick, short, or barbed-wire looking roots which can be mistaken for chemical damage. Work has shown that soils high in soluble iron (Fe), or plants that are taking up higher levels of Fe can increase that plants tolerance of Cu, thus lessening the toxic effect. In situations where toxic soil levels of Cu exist, the leaf analysis may not properly reflect the severity of the problem because the root damage can become self-limiting to Cu uptake. If the field has a history of having been a vineyard, orchard, or other crop where “Bordeaux Mix” may have been used for many years, you may find excess soil Copper. While you can’t remove excess Cu from the soil, it may be beneficial to treat high-Cu soils with practices and materials that tie-up Cu as listed under factors affecting availability. For example, applying excessive rates of P, Zn, OM, and maybe Fe, might help.

Using Copper in a Fertility Program

Soil testing is the first step in determining a need. Plant analyses are also useful, and when a need is determined treatment should follow.

Recommended rates of Cu are:

Broadcast:	2 to 10 lb./A
In-row:	1 to 5 lb./A
Foliar:	0.1 to 0.25 lb./A

While correcting Cu problems is fairly straight-forward, remember that **excess Cu applications can easily damage plant roots and leaves**, so proper application rates and methods are important. Soil applications of Copper materials can have an extremely long residual effect in the soil. Therefore, **when Cu applications are being made, annual soil testing is needed to monitor soil Cu buildup.** If a foliar Cu product is "basic" in nature (the pH of the Copper product/carrier mixture is greater than 7.0), the potential for, and severity of foliar damage can be reduced. Many times application of appropriate Cu-containing fungicides are effective foliar nutrient treatments, for mildly low leaf Cu conditions.

Copper Fertilizer Sources

Product	Chemical Formula	Typical Copper Content
Copper Sulfate Monohydrate	$CuSO_4•H_2O$	35%
Copper Sulfate Pentahydrate	$CuSO_4•5H_2O$	25%
Cupric Oxide	CuO	75%
Copper Chelates	CuEDTA	8-13%

Manganese (Mn^{++})

Functions

Manganese is essential for many plant functions. Some of them are…

1. The assimilation of carbon dioxide in photosynthesis.
2. It aids in the synthesis of chlorophyll and in nitrate assimilation.
3. Manganese activates fat forming enzymes.
4. It functions in the formation of riboflavin, ascorbic acid, and carotene.
5. It functions in electron transport during photosynthesis.
6. It is involved in the Hill Reaction where water is split during photosynthesis.

Deficiency Symptoms (no photo available)

Because Mn is not translocated in the plant, deficiency symptoms appear first on younger leaves. The most common symptoms on most plants are interveinal chlorosis. The symptoms can progress to showing brown areas in the younger leaves. No photo is available, but the symptoms would be similar to Fe deficiency, shown in a later section.

Factors Affecting Availability

1. **Soil pH:** Much of the literature on micronutrients will state that high pH reduces Mn availability. While this is true, within the normal soil pH range at which blueberries are grown, soil pH is not a factor in Mn availability. There are some soils and situations where a soil pH below the desired range for blueberries might increase Mn availability to a point where it might interfere with the uptake of Fe.
2. **Organic Matter:** Mn can be "tied up" by the organic matter such that high O.M. soils can be Mn deficient.
3. **Soil Moisture:** Under short-term waterlogged conditions, plant available Mn^{++} can be reduced to Mn^{+}, which is unavailable to plants. However, under long-term reducing (e.g. waterlogged) conditions, available Mn can be increased. As soil dries, Mn availability undergoes changes. Some unavailable Mn^{+} is oxidized to available Mn^{++}, while some available Mn^{++} can be oxidized to unavailable Mn^{++++}. When the soil is in transition from flooded to normal moisture content, there can be a temporary "flush" of excess Mn^{++} giving the possibility of a temporary toxicity, especially if other conditions are favorable to the presence of excess Mn^{++}.
4. **N Stress:** Low N availability decreases the vigor of plants to an extent that it may fail to take up adequate amounts of many other nutrients. Manganese uptake can be affected in this way.
5. **Mn:Fe Balance:** Soils high in available Iron (Fe) or high Fe applications can reduce Mn uptake. The reverse can also occur.
6. **Mn:P Balance:** There is conflicting research that high soil P can either increase, or decrease Mn uptake by various plants species. Until more definite evidence is available, we probably should not include the soil P level in our consideration of Mn availability.
7. **Mn:Zn Balance:** There is conflicting research high soil Zn can either increase, or decrease Mn uptake by various plant species. Until more definite evidence is available, we probably should not include the soil Zn level in our consideration of Mn availability.
8. **Mn:Mo Balance:** One researcher observed that Mn concentrations were reduced in half by molybdenum (Mo) fertilization. This limited evidence should not be used to make Mo recommendations.
9. **Mn:Si Balance:** While silicon (Si) is not considered an essential element for blueberries or most other crops, research has shown that Si applications can alter the Mn distribution in leaf tissue in such a way as to reduce the possibility of Mn toxicity from excess Mn uptake. This would suggest that if Mn is not at toxic levels, Si could also induce a Mn shortage.
10. **Mn:S Balance:** The Sulfur (S) interaction is primarily one-way, as the S content of the plant is diminished so also is the Mn content.
11. **Mn:Anion Balance:** Heavy fertilization with materials containing Cl^{-}, NO_3^{-}, SO_4^{--}, can also enhance Mn uptake (termed the anion effect). Of course, chlorides (Cl^{-}) should not be applied to blueberries because of direct Cl toxicity potential, and nitrates (NO_3^{-}) are not as efficient as ammonium (NH_4^{+}) for blueberries and large N applications in general are normally not needed. Therefore, sulfate applications would seem to be the only nutrient in this relationship that might be worth watching.

Toxicity

Acid soil is the most common cause of Mn toxicity with most plant species. Because blueberries have evolved with and become adapted to strongly acid soils, Mn toxicity is not common. Symptoms include chlorosis and necrotic lesions on old leaves, dark-brown or red necrotic spots, accumulation of small particles of MnO2 in epidermal cells of leaves or stems, often referred to as “measles”, drying leaf tips, and stunted roots. Sometimes the interveinal tissue will show "puckering" or raised areas in the leaves. Toxic symptoms can sometimes be alleviated by using Iron chelates applied to either the soil or preferably the foliage. While blueberries do not necessarily require extremely high levels of Mn in their tissue, they are able to tolerate higher levels than most other plant species.

Mn Toxicity Symptoms in Blueberry

Using Manganese in a Fertility Program.

Recommended rates of Mn are:

Broadcast:	NOT RECOMMENDED
In-row:	2 to 5 lb./A
Foliar:	1 to 2 lb./A

Broadcast applications are not recommended because Mn that is not concentrated in a band or similar method is quickly converted to unavailable forms when it comes into contact with the soil. Soil pH is the dominant controlling factor in Mn availability in nearly all soils. Therefore, if a blueberry crop is found to be low in Mn, it is very likely that the soil pH is too high. In nearly all situations, acidifying the soil will correct a Mn shortage and applying Mn fertilizer to the soil will normally not correct the problem if the soil pH is too high for blueberries. Where foliar Mn is used, multiple applications throughout the season are often needed to compensate for soil deficiencies. Many times application of appropriate Mn-containing fungicides are effective foliar nutrient treatments, for mildly low leaf Mn conditions.

Manganese Fertilizer Sources

Product	Chemical Formula	Typical Mn Content
Manganese Sulfate	$MnSO_4 \cdot 4H_2O$	23-28%
Manganese(manganous) Oxide	MnO	41-68%
Manganese Chelate	various	5-12%

Note: There have been anecdotal reports that if a Mn-chelate (EDTA) is added to the soil to correct an apparent deficiency problem, it may result in increased Mn deficiency. This is supposed to occur because the affinity of some chelating materials for iron is greater than their affinity for manganese and substitution occurs after soil application. The resulting new Fe-chelate is rapidly taken up by the plant and the ensuing interaction increases the Mn deficiency. We cannot confirm this information and suggest that the grower discuss this possibility with suppliers and producers of Mn chelates.

Zinc (Zn^{++})

Functions

Zinc is essential for many plant functions. Some of them are…

1. Production of Auxins, an essential growth hormone.
2. It activates enzymes in protein synthesis, plus is involved in the regulation and consumption of sugars
3. It is necessary for starch formation and proper root development.
4. Zn influences the rate of seed and stalk maturation.
5. It is necessary for the formation of chlorophyll and carbohydrates.
6. The presence of adequate amounts in the tissue enables the plant to withstand lower air temperatures.

Deficiency Symptoms (no photo available)

Visible Zn deficiency symptoms in production fields are not well documented. Symptoms induced experimentally include chlorosis in the younger leaves that is similar to Fe and Mn deficiency. Zinc chlorosis is different in that it appears uniformly across the entire leaf, without the interveinal pattern associated with Fe and Mn. Most broadleaf crops with Zn deficiency also exhibit much smaller than normal terminal leaves. It would seem reasonable to expect that blueberries would have the same symptom.

Factors Affecting Zn Availability

1. **Soil pH:** Much of the literature on micronutrients will state that high pH reduces Zn availability. However, within the normal soil pH range at which blueberries are grown, soil pH is not a factor in Zn availability.
2. **Zn:P Balance:** High levels of soil P can reduce Zn uptake. There is not a specific soil P level at which this occurs under all conditions.
3. **Organic Matter:** Organic matter is a source of Zn, and the organic compounds in O.M. can chelate inorganic sources of Zn which increases their availability.
4. **N Stress:** Low N availability decreases the vigor of plants to an extent that it may fail to take up adequate amounts of many other nutrients. Zinc uptake can be affected in this way.
5. **Soil Saturation:** While Zn does not undergo the valence changes that Mn does in saturated soils, and this effect has not been demonstrated in blueberries, research has shown that rice cannot take up Zn as effectively under flooded conditions. The causes of this condition would seem to be applicable to blueberries and other crops.
6. **Zn:Cu Balance:** Plant roots appear to absorb Zn and Cu by the same mechanism. This causes interference in the uptake of one when the other is in excess in the root zone.
7. **Zn:Mn Balance:** The following has been reported for crops other than blueberries, and might also apply to blueberry nutrition. Research results have indicated evidence of interactions between Zn and Mn. Some results indicate an antagonistic relationship, while others indicate a sympathetic relationship. Certain work indicates that specific cultivars within some species may have a stronger reaction to soil Zn:Mn balances.
8. **Zn:Mg Balance:** It has been reported that additions of Mg can increase the uptake of Zinc in some crops.
9. **Zn:As Balance:** High levels of arsenic (As) in the soil, as might be found in old orchard soils, can seriously inhibit both Phosphorus and Zinc uptake. However, since soil P is often high and Zn may not be, the effect may be more commonly seen as decreased Zn uptake.

Toxicity (no photo available)

Zn toxicity is relatively rare under normal field conditions, however it has been observed after unusually high or prolonged applications. It has also occurred in crops, other than blueberries, grown near abandoned zinc mines. Reported symptoms are chlorotic and necrotic leaf tips, interveinal chlorosis in new leaves, retarded growth of the entire plant, and root injury causing tip death of laterals, resulting in the “barbed wire” appearance. However, excessive Zn availability or uptake could just as easily cause deficiencies of other nutrients such as P or another cation micronutrient, resulting in their deficiency symptom being the only apparent symptom. Sewage sludge has been used with success on some other crops to decrease Zinc availability. However, this might be due in part or in total to lime treated sludge increasing the soil pH. This is not acceptable with blueberries. Another potential option for reducing Zn uptake could be to increase the soil P test to higher than needed levels.

Using Zinc in a Fertility Program

Recommended applications rates include:

Broadcast	2 to 10 lb./A
In-row	1 to 5 lb./A
Foliar	0.25 lb./A to 1% solution

Zinc is sometimes applied broadcast at much higher rates than listed above. Normally this is done to correct the soil Zn level in one treatment. This approach can be effective in correcting Zn problems for many years. Zinc-oxides and oxy-sulfates are satisfactory for buildup purposes, but for in-row applications or if immediate uptake is needed, the sulfate or chelate forms should be used. Remember, as far as the soil application of chelates are concerned; a pound of Zn is a pound of Zn. Chelates are often less prone to causing leaf damage when applied foliar. Many times application of appropriate Zn-containing fungicides are effective foliar nutrient treatments, for mildly low leaf Zn conditions.

Zinc Fertilizer Sources

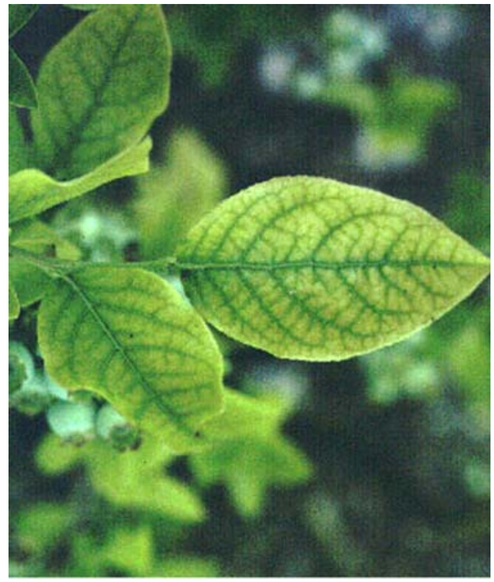
Product	Chemical Formula	Typical Zn Content
Zinc Sulfate	$ZnSO_4 \bullet H_2O$	36%
Zinc Oxy-Sulfate	$ZnO+ZnSO_4 \bullet H_2O$	38-50%
Zinc Oxide	ZnO	50-80%
Zinc EDTA Chelate	ZnEDTA	6-14%
Zinc HEDTA Chelate	ZnHEDTA	6-10%

Iron (Fe^{++})

Functions

Iron is essential for many plant functions. Some of them are…

1. Chlorophyll development and function.
2. It plays a role in energy transfer within the plant.
3. It is a constituent of certain enzymes and proteins.
4. Iron functions in plant respiration, and plant metabolism.
5. It is involved in nitrogen fixation



Fe Deficient Blueberry

Deficiency Symptoms

Interveinal chlorosis of young leaves. Severe deficiencies may progressively affect the entire plant turning the leaves from yellow to bleached-white.

Factors Affecting Availability

1. **Soil pH:** Much of the literature on micronutrients will state that high pH reduces Fe availability. However, within the normal soil pH range at which blueberries are grown, soil pH is not a factor in Fe availability. However, the acid soils required by blueberries may cause excessive available Mn, which can lead to Fe shortages due to micronutrient competition (see item 7 below).
2. **Low Organic Matter:** In addition to being a source of Fe, organic matter compounds are able to form Fe complexes that improve availability.
3. **Saturated, Compacted, or Other Poorly Aerated Soils:** In acid soils, poor soil aeration can increase Fe availability to the point of interference with other nutrients or direct toxicity.
4. **High Soil P:** Excessive amounts of soluble P or high rates of P fertilizer have been demonstrated to inhibit Fe uptake in many crops.
5. **Form of N Applied:** While not likely to be a significant factor in blueberry nutrition, increased NO_3-N uptake can reduce Fe uptake by causing an anion-cation imbalance in the plant.
6. **Fe:Zn Balance:** Zn deficiency has been shown to increase the Fe uptake of many crops, sometimes to the point of toxicity. Conversely, high Zn availability reduces Fe uptake.
7. **Fe:Mn Balance:** It is well documented that these two elements are antagonistic, and one will inhibit the uptake of the other (see item 1).
8. **K:Fe Balance:** K appears to play a very specific, but poorly understood role in the utilization of Fe. Some research indicates that low K availability can result in increased Fe uptake by various crops.
9. **Fe:Mo Balance:** In normal situations, this is not likely to be a concern to blueberry crops. However, high levels of available Mo can reduce the uptake of Fe by causing the precipitation of iron molybdate on the root surfaces. This is especially important in alkaline soils (not found in blueberries) where the high pH reduces the availability of Fe while increasing that of Mo.
10. **Bicarbonates (HCO_3^-):** This interference with Fe nutrition should never be a concern to blueberry crops, because it will only happen in very high pH or salty soils (saline and alkali conditions). Iron deficiency can be induced by the presence of excess amounts of bicarbonate in the soil.

Toxicity Symptoms

Iron toxicity is primarily pH related and occurs where the soil pH has dropped sufficiently to create an excess of available Iron. As with some other nutrients, the visible symptoms of Fe toxicity are likely to be a deficiency of another nutrient. Fe toxicity can also occur when Zinc is deficient, or the soil is in a "reduced" condition. Reduced soil conditions mean that the soil lacks adequate oxygen. This can be caused by very wet or flooded conditions and soil compaction (or more typically, both situations). We don't have good examples of the visual symptoms of Fe toxicity in blueberries, but in other plant species it has resulted in stunted growth of tops and roots plus dark green or dark brown to purple foliage.

Using Iron in a Fertility Program

Luckily, most agricultural soils provide an abundant supply of Fe to plants. Iron fertilizer can be more difficult to use in a fertility program than other nutrients. Most soil application methods are often not very effective, while the required multiple foliar applications are often expensive and labor intensive.

Recommended Rates

Broadcast:	Not Recommended
In-row*:	Follow label rates
Foliar**:	1.0 to 2.0 lb./A

*Certain proprietary chelated Fe products appear to be effective when applied in a concentrated band similar to row fertilizer in annual crops. Otherwise only foliar Fe is recommended.

**Foliar sprays should include a wetting agent and the pH of the solution should be below pH 7.0. Be sure to test the mixture for precipitation before using.

Both chelates and citrate acidified (reduced) sulfates are effective for foliar applications. Cost is the primary factor. Avoid the use of sulfates, or solutions which have a rusty color. This often indicates that the Fe has oxidized and the spray material may not be fully available to the crop.

Iron presents some difficulties for plant analysis also because (1) it is often a contaminate on samples that have any dust on them, (2) Fe can exist in a leaf in a non-functional form, and (3) a crop may respond to foliar Fe due to a low Fe:Mn ratio in the tissue, even when Fe is adequate by “critical level” standards.

If visible Fe deficiency symptoms are present, a significant yield reduction has already occurred. Since multiple foliar applications per season are often needed to prevent Fe deficiencies, it is often best to identify the cause of the Fe shortage and correct that problem. As stated earlier, the underlying cause of a Fe deficiency is not likely to be a simple shortage of Fe in the soil. Normally Fe shortages are caused by problems such as drainage, soil pH, or interaction with other nutrients.

Iron Fertilizer Sources

Product	Chemical Formula	Typical Iron Content
Ferrous Sulfate	FeSO4•7H2O	20%
Ferrous Ammonium Sulfate	FeSO4•7H2O $(NH_4)_2SO_4$	14%
Iron DPTA Chelate	FeDPTA	10%
Iron HEDTA Chelate	FeHEDTA	5-12%

Molybdenum (MoO_4^-)

Functions

Molybdenum is essential for many plant functions.

1. It functions in converting nitrates (NO_3) into amino acids within the plant.
2. It is essential to the symbiotic nitrogen fixing bacteria in legumes.
3. It is essential to the conversion of inorganic P into organic forms in the plant.

Molybdenum is considered to be quite mobile within a plant as it moves readily in both the xylem and phloem conductive tissue of the plant. Still its highest concentration is in mature leaves because it binds readily with sulfur-containing amino-groups, sugars, and polyhydroxides which are usually in greater concentration in these leaves. It is found in the enzymes nitrate-reductase and nitrogenase which are essential for nitrate reduction and symbiotic N fixation in legumes. **Adequate Molybdenum minimizes the presence of nitrites and nitrates in plant tissues.**

Deficiency Symptoms (no photo available)

Little or no information is available on Mo deficiencies specific to blueberries. Therefore, the following symptoms are described for plants other than blueberries. While it is probable that blueberry symptoms of Mo deficiency would be similar, this may not be the case.

1. Chlorosis of leaf margins, or more general chlorosis, similar to typical N deficiency in some cases.
2. Fired margin and deformation of leaves due to excess NO_3
3. Destruction of embryonic tissue.
4. Poor fruit set, due to less viable pollen

Foliar deficiency symptoms are somewhat rare and positive responses may occur where there are no visible symptoms.

Factors Affecting Availability

1. **Leaching Soil Conditions:** Available soil Mo is an anion, and is therefore leachable.
2. **Soil pH:** Molybdenum is the only micronutrient in which the availability increases as the pH increases. While not likely to affect blueberries, and rare in any crop, unnecessary Mo applications when the soil pH is above 6.5 can result in Mo toxicity to the crop. At pHs below 6.0, availability is rapidly diminished because Mo is easily "fixed" in the soil by free iron and aluminum compounds [Fe $(OH)_3$, AI$(OH)_3$ and Fe_2O_3].
3. **Soil Saturation**: It is believed by some researchers that in saturated soils, Mo availability is increased somewhat.
4. **Mo:S Balance:** Some work has shown that sulfate applications can cause a reduction in Mo uptake by plants. While this has not, to our knowledge, been demonstrated in blueberries, they often receive significant amounts of S applications and may be subject to this interaction.
5. **Mo:P Balance:** Applications of P have increased the Mo content of some other plant species. It is thought that P reduces the adsorption of Mo compounds in the soil, thus making Mo more available for plant uptake. Again, while the subject crops were not blueberries, they may be subject to the same effects.
6. **NH_4:NO_3 Balance:** Plants can often grow well in low Mo soils when fertilized with NH_4 fertilizers, as opposed to NO_3 fertilizers. This would seem to relate directly to blueberries and may offset other Mo-negative conditions that are typically present in blueberry soils.

Toxicity Symptoms

Marginal leaf scorch, yellowing or browning, and eventual leaf drop as found in typical salt damage. The application of S can decrease Molybdenum uptake and minimize the incidence of toxicity.

Using Molybdenum in a Fertility Program

Most analytic laboratories presently, do not offer soil analysis for Molybdenum on a routine basis. The more capable labs may offer it as a special request. Most soil analytic techniques lack well calibrated interpretive methodology (the correlation between extractable Mo and crop response is the weakest of all the essential nutrients). Plant analyses are a better choice. But, it too is not as well worked out as other nutrients. Generally speaking, tissue levels over 1.0 ppm are considered adequate.

Molybdenum Fertilizer Sources

Product	Chemical Formula	Typical Mo Content
Sodium Molybdate	$Na_2MoO_4 \cdot 2H_2O$	39%
Molybdenum Trioxide	MoO_3	66%
Ammonium Molybdate	$(NH_4)_6Mo_7O_{24} \cdot 2H_2O$	54%

TYPICAL APPLICATION RATES OF ELEMENTAL Mo

Broadcast	2.3 to 4.7 oz./Acre
Foliar	0.4 to 1.2 oz./Acre

Chloride (Cl^-)

Since chlorides can easily be toxic to blueberries, it is not expected that any grower should need to apply Cl to a blueberry crop. However, Cl is an essential nutrient for all crops. The following information is included to simply complete the information for all of the essential nutrients. It is taken from our paper on secondary and micronutrients, and as such includes references to crops other than blueberries.

Chloride is the most recent addition to the list of essential elements. Many people make the common mistake of confusing the plant nutrient chloride (Cl^-), with the toxic form chlorine (Cl). Chlorine is not the form that plants use. Chlorine exists either as a gas, or dissolved in water, such as bleach, and is not found in fertilizer. Although Chloride is classified as a micronutrient, plants may take-up as much Chloride as secondary elements such as Sulfur.

Function

Chloride is essential for many plant functions. Some of them are…

1. It is essential (working in tandem with K^+) to the proper function of the plants stomatal openings, thus controlling internal water balance.
2. It also functions in photosynthesis, specifically the water splitting system.
3. It functions in cation balance and transport within the plant.
4. Research has demonstrated that Cl diminishes the effects of fungal infections in an, as yet undefined, way.
5. It is speculated that Cl competes with nitrate uptake tending to promote the use of ammonium N. This may be a factor in its role in disease suppression, since high plant nitrates have been associated with disease severity.

Deficiency Symptoms (no photo available)

Wilting, restricted and highly branched root system, often with stubby tips. Leaf mottling and leaflet blade tip wilting with chlorosis has also been observed. Chloride insufficiency in cabbage is marked by an absence of the cabbage odor from the plant.

Factors Affecting Availability

Most soil Cl is highly soluble and is found predominantly dissolved in the soil water. Chloride is found in the soil as the Chloride anion. Being an anion it is fully mobile except where held by soil anion exchange sites (Kaolinite clays, Iron and Aluminum Oxides). In areas where rainfall is relatively high and internal soil drainage is good, it may be leached from the soil profile. Also, where muriate of potash fertilizer is not regularly applied Chloride deficiencies can occur. Atmospheric Chloride deposition tends to be rather high along coastal regions and decreases as you progress inland. Chloride, nitrate, sulfate, boron, and molybdenum are all anions in their available forms, and in that form they are antagonistic to each other. Therefore, an excess of one can decrease the availability of another. Little information is available on other specific interactions that may occur.

Toxicity Symptoms (no photo available)

Toxic symptoms are similar as is found with typical salt damage. Leaf margins are scorched and abscission is excessive. Leaf/leaflet size is reduced and may appear to be thickened. Overall plant growth is reduced. Chloride accumulation is higher in older tissue than in newly matured leaves. In conifers, the early symptoms are a yellow mottling of the needles, followed by the death of the affected needles.

Chloride Fertilizer Sources

Product	Chemical Formula	Typical Chloride Content
Sodium Chloride	$NaCl$	61%
Potassium Chloride	KCl	47%
Calcium Chloride	$CaCl_2$	64%

Soil and Plant Analyses do not routinely include Chloride analyses but, most laboratories are able to accomplish the assessment. Although interpretative data are limited, soil and plant analyses can be useful, especially where specific questions arise. Be aware that insufficiencies do not usually exist where muriate of potash fertilizer is routinely used or in saltwater coastal areas where atmospheric deposition is occurring.

In areas where deficiencies are known to exist, 30 to 100 lb./Acre of Chloride per year will supply the needs of responsive crops. Response may be improved if the application is split. For example 30 lb./A fall applied Cl^- and 70-80 lb./A spring applied can improve wheat yields over single applications.

Other Elements

Other elements have shown to have a positive effect on the growth of some plant species, or to be able to substitute for other essential elements in some plants, to some degree. These elements include...

Sodium (Na)	**Aluminum (Al)**
Silicon (Si)	**Nickel (Ni)**
Cobalt (Co)	**Lanthanum (La)**
Cerium (Ce)	

To date researchers have not seen enough evidence to call these elements essential, but the list of essential elements may expand as knowledge is expanded. Excesses of these elements, like many of the micronutrients, can also be damaging to plant growth. This is well documented for Sodium and Aluminum.

Aluminum deserves special attention with blueberries because of the very acid soil pH which the crop requires. At these acid pH's, there is often a considerable amount of soluble Al in the soil solution. This can cause several negative results. First, soluble Al has a strong affinity for soluble P. This is the same form of P that the blueberries require. The result of the excess soluble Al can be the requirement for a higher soil P test than suggested by us and other authorities. Another potential problem is the cation competition caused by excessive soluble Al. The likely result of this cation competition is reduced uptake of one or more of the cation micronutrients (Cu, Mn, Fe, and Zn). About the only way to identify either of these potential problems is with leaf analysis.

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