

TREE FRUIT SOIL FERTILITY AND PLANT NUTRITION IN CROPPING ORCHARDS IN CENTRAL WASHINGTON



Healthy trees need healthy roots to take up water and nutrients; healthy soils to provide water, nutrients, and protection from plant pathogens; sufficient water; and exemplary horticulture. When considering tree nutrition, it is essential to start with standard soil and tissue diagnostics. These tools are often more valuable when used together, when coupled with observations of the tree, and when results are monitored over time for trends.

There are many ways to create a tree fertility program. This publication will describe a strategy with five steps:

1. Know the common nutritional needs for your area
2. Apply maintenance nutrient sprays
3. Maintain optimal soil fertility levels
4. Fertilize trees based on nutrient demand minus supply
5. Monitor nutrient management program

1. Know the Common Nutritional Needs for Your Area and How to Best Determine Needs

It is important to be familiar with the soils in your region to predict potential deficiencies. In central Washington, where most Washington orchards occur, the soils are generally relatively young (less than 12,000 years old). These young soils are rich in minerals which become available over time providing phosphorus, potassium, and micronutrients. However, they are also often extremely well drained which leads to leaching of highly soluble nutrients like boron and nitrogen.

The following list briefly describes regional characteristics for major and minor nutrients and how to best determine needs in central Washington:

Nitrogen (N) demand often exceeds the natural supply in tree fruit crops and should be supplied in most Pacific Northwest growing conditions. The larger source of N in the soil comes

from the mineralization of the organic matter, which is generally low in eastern Washington soils, ranging from 0.1% to 3%. Symptoms of N deficiency are lack of growth and generally yellowing leaves, starting with the older leaves. Excess N can create excessive vigor and affect fruit quality.

pH is often high in central Washington due to calcareous soils. Use soil analysis to determine levels.

Phosphorus (P) is generally not a problem in central Washington orchards. Soil mineralization often provides sufficient P for tree fruit crops. Symptoms of P deficiency are reduced growth, and, opposite to all other nutrient deficiencies, dark green leaves. There are several tests for P availability; however, P-Olsen testing is recommended in the high pH soils of central Washington.

Potassium (K) deficiency is common in East Coast and Midwest orchards but is infrequent in Washington orchards. It can appear in older orchards where long-term use of very high-quality irrigation water, coupled with removal of K in the fruit crop, has depleted soil K (e.g., the Entiat River valley and similar eastern Cascade mountain valley settings). It can also become apparent on very sandy soils, which are naturally low in K, where large amounts of irrigation or evaporative cooling water are used. The relatively small root volume of dwarfing rootstocks, particularly in drip-irrigated orchards, also may lead to lower K availability than historically documented. Symptoms of K deficiency are first observed in older leaves as yellowing or necrosis of leaf margins. Use soil tests, visual examination, leaf analyses, and site history to determine status.

Calcium (Ca) is generally high in many soils in central Washington since it is a component of caliche or lime (CaCO_3) in soils. Depending on its source, irrigation water can also contain appreciable amounts of Ca. However, deficiencies can be observed in sandy and acidic soils. Soil testing is a useful tool to determine soil Ca levels. Because Ca deficiency disorders (e.g., bitter pit in apples, cork sport in pears) are related to within-tree partitioning imbalances, Ca spray applications are frequently utilized even when soil Ca levels are adequate. Vigor,

crop load, and irrigation should be optimized to avoid Ca deficiency disorders.

Magnesium (Mg) deficiency is infrequent in Washington orchards. It can be induced by over-applications of lime. Excess amounts of Ca or K in soils may compete with Mg for root uptake. Use dolomite (Ca-Mg carbonate) or Mg calcite (calcite with about 10% Mg) if Mg is deficient in the soils. Visual symptoms of deficiency appear in older leaves first as interveinal chlorosis, very distinctive in apples around over cropped spurs. Leaf tissue analysis can indicate if Mg is low.

Sulfur (S) deficiency has been detected in some orchards in eastern Cascade mountain valleys irrigated with very pure water (e.g., Manson and Wenatchee River valleys). Visual symptoms of S deficiency are similar to N deficiency. Use soil and leaf tissue testing to assess S needs. Occasional use of S based fertilizer (gypsum, ammonium sulfate, zinc sulfate, etc.) will prevent or correct deficiencies.

Boron (B) deficiency will eventually occur in most central Washington orchards if maintenance applications are not applied. B deficiency is particularly a problem in pears which need relatively high levels of B for adequate fruit set. Symptoms of B deficiency and toxicity are similar: leaf distortion, death of growing points, poor ovule fertilization, fruit set, and deformed fruit. Boron levels can be quickly depleted due to excessive application of irrigation or evaporative cooling water in coarse or sandy soils. Fruit trees are normally able to absorb sufficient soil-applied B even if some portion is lost due to leaching. Soil testing for B can be used to determine toxicity and deficiency in medium- to fine-textured soils. Leaf tissue B levels usually give a good indication of tree B status.

Zinc (Zn) deficiencies are common in Washington orchards. Visual symptoms of Zn deficiency (blind wood, little-leaf, and rosettes) are distinctive. Tissue test levels of Zn are a good indicator of deficiency or toxicity; however, Zn spray residues can lead to inaccurate interpretation when sampling within 15 days of a foliar spray. In high pH soils, Zn is poorly related to tree Zn status. Regular use of Zn maintenance sprays is recommended in high pH soils.

Copper (Cu) deficiencies are rare but can occur in Washington orchards that have unusually high organic matter levels, such as those planted on former cattle feedlots. Excessive Cu in soils can lead to antagonisms with other metals (Fe, Zn, Mn). Soil and tissue test of Cu are good indicators of deficiency or toxicity; however, Cu spray residues can lead to inaccurate interpretation due to contamination from pesticides containing Cu. Avoid collecting samples after pesticide sprays containing Cu.

Manganese (Mn) deficiencies appear to be uncommon in Washington orchards. If it does appear, it is most likely to show up in calcareous soils, and its visual symptoms may be masked by Fe deficiency symptoms. Acid soils or anaerobic conditions can lead to Mn toxicities due to an increased solubility and availability for plant uptake. Tissue testing can be a useful indicator of tree Mn status.

Iron (Fe) deficiencies are common in central Washington and often are linked to over-watering, perched water tables, or calcareous soils. Over-watering and perched water tables reduce soil oxygen and generate bicarbonate, leading to Fe precipitation. Its presence and severity may vary from year-to-year, depending on variations in rainfall and irrigation water management. Soil and leaf tissue tests are not definitive and have not shown a good correlation with active Fe and nutrient deficiency. Deficiency symptoms are distinctive, starting in young leaves as intense chlorosis, and, in severe cases, with leaves turning almost white with green veins. Soil physical properties and soil pH are generally the best indicators of tree Fe status.

Sodium (Na) in high amounts can lead to increased salinity and sodicity in soils. High salinity can affect root growth, water uptake, and plant cell death, while soil sodicity affects soil aggregation and stability. High sodium has been detected in areas irrigated with water from the Columbia Basin Irrigation Project. It has also been seen in areas near Ellensburg and Pasco where the irrigation water is derived from deep aquifers in basalt bedrock. Na toxicity symptoms are necrotic margins of leaves. Soil exchangeable sodium percentage (ESP), which relates its content with the cation exchange capacity (CEC), and water analyses are good indicators of high sodium.

2. Apply Maintenance Nutrient Sprays to Meet Regional Needs

Boron. Small annual foliar application is recommended. Optimal timing is during bloom for most tree fruit, and any time of year is appropriate for apples. Keep adequate levels in the soil for root growth (see Table 1). Excess B can lead to severe toxicity, so application rate should be carefully calculated. Fertigation can also lead to uneven distribution and toxicity (around leaks and junctions) and is not recommended. See [Boron Nutrition in Deciduous Tree Fruit Orchards](#) for boron application recommendations (Peryea 2018a).

Zinc. Annual foliar applications are recommended in calcareous or high pH soils. Preferred timing is late dormant (stone fruit), silver-tip (apples and pears), and post-harvest (all tree fruits except for apricot). Zn sprays should be avoided during the growing season unless deficiency symptoms occur. Zn sulfates are common but can cause tissue damage when temperatures are greater than 85°F after the application. Zn sulfate is also not compatible with dormant oil or lime sulfur. Zn chelates are also available and are less likely to cause russet. See [Think Zinc!](#) for zinc application recommendations (Peryea 2018b).

Calcium. In order to reduce Ca-related disorders, such as bitter pit in apples and cork-spot in pears, Ca foliar sprays and postharvest treatments are generally utilized in tree fruit. See the [WSU Crop Protection Guide](#) for application recommendations (2019).

3. Maintain Optimal Soil Fertility Levels

Most nutrients are absorbed primarily through the root system. Soil availability of essential nutrients is the most efficient way to ensure fruit tree growth, with some exceptions (above). Soil analyses can measure soil nutrient levels and be compared to levels where research has shown sufficient availability, deficiencies, or toxicities. A soil test will indicate if the elements evaluated are present in adequate, deficient, or excessive amounts (Marschner 1995) but will not indicate how much nutrient the plant is absorbing or if there are other biotic or abiotic factors affecting the orchard.

Soil tests are excellent tools to determine the levels of nutrients with low to moderate mobility in the soil.

In central Washington orchards, soil testing is most accurate for:

- **pH**
- **Organic Matter**
- **Electrical Conductivity (EC)**—an indicator of salinity
- **Phosphorus (P-Olsen)**
- **Potassium**
- **Calcium**
- **Magnesium**
- **Boron** (except for coarse and sandy soils)
- **Copper** (for toxicity)

In central Washington, additional interpretation is needed for:

- **Boron.** As indicated previously, B soil testing in sandy soils is not a good indicator due to its high mobility, thus, tissue testing is better suited to identify toxicity or deficiency.
- **Sulfur.** In sandy soils with high sulfate mobility, complement with foliar analyses.
- **Metallic micro nutrients (Zn, Fe, Mn, Cu).** High levels of volcanic ash in some central Washington soils and alkaline soils can tie up metals and make them unavailable to trees. Complement with foliar analyses or visual symptoms.

Nitrate (NO₃) and ammonium (NH₄) are the two primary forms of available N for plants. Both elements can be measured in the soil. These forms correspond to the inorganic N, and they are continually changing. Due to the mobility and variability, their analysis in the soil will only represent the specific moment when the sample was collected and does not correlate well with the soil supply. A better indicator for N is the organic matter (OM) present in the root zone; however, its mineralization depends on many factors, such as soil moisture, temperature, and microbiome composition, thus, making it hard to predict.

Use soil fertility analysis to ensure that nutrient levels are maintained in adequate ranges (Table 1). Foliar recommendations generally assume that soil contains adequate amounts of nutrients and healthy root systems. The following table provides levels considered optimum for tree fruit and can be used as a guideline to ensure adequate nutrient supply. When utilizing soil testing, it is important to make sure you are comparing the same method and units. Here, we utilized the [Soil, Plant and Water Reference Methods for the Western Region](#) by Gavlak et al. (2005). (For more details on methods differences, visit [The North American Proficiency Testing Program](#).) Soil testing alone should not be used to determine the nutritional status of the orchard.

Table 1. Recommended soil test levels and testing methods for tree fruit.

Soil test	Unit	Low	Optimal	Excessive	Method ^a
pH	-	< 5.0	6.0–7.5	> 8.0	1:1/CaCl
EC paste	mmhos/cm	-	< 2.6	> 4	Paste
EC 1:2.5 or 1:1	mmhos/cm	-	< 0.5	> 1	1:1
P-Olsen ^b	ppm	< 10	15–40	> 50	NaHCO ₃
Potassium (K)	ppm	< 120	150–250	> 300	NH ₄ OAc
Potassium (K)	meq/100g	< 0.3	0.4–0.6	> 0.7	NH ₄ OAc
Calcium (Ca)	meq/100g	< 3.0	4.1–20		NH ₄ OAc
Magnesium (Mg)	meq/100g	< 0.5	0.5–2.5	> 2.5	NH ₄ OAc
Sodium (Na)	meq/100g		< 0.5	> 0.5	NH ₄ OAc
Boron (B)	ppm	< 1.0	1.0–1.5	> 1.5	CaCl 0.01 mol/L
Sulfur (S) ^c	ppm	< 4	9–20	> 20	Ca ₃ (PO ₄) ₂
Zinc (Zn)	ppm	< 0.25	0.6–1.0		DTPA
Copper (Cu)	ppm	< 0.1	0.6–1.0	> 20	DTPA
Manganese (Mn)	ppm		1–5	> 50	DTPA
Iron (Fe) ^d	ppm	> 4.5	-	-	DTPA
Molybdenum (Mo)	ppm		0.11–0.20	-	DTPA

^a Methods: derived from *Soil, Plant and Water Reference Methods for the Western Region*, 2005, by Gavlak et al.

^b P-Olsen is recommended for the mildly acid to alkaline soils of eastern Washington (Gavlak et al. 2005).

^c The method has a detection limit of 2.0 mg kg⁻¹ (dry basis) and is generally reproducible to within ± 15%. Better to look at in-tissue analysis.

^d Soil analyses for Fe do not correlate well with Fe availability.

Note: mg/kg = ppm. ppm = meq/100 g*MW/charge*10.

Nutrient availability in the soil is greatly controlled by the cation exchange capacity of soils (CEC), type of clay present, and soil mineral content. Within the cation pool (Ca^{2+} , Mg^{2+} , Na^+ , and K^+), when one is excessive in relation to the other, it can lead to cation antagonism. Excessive fertilization, over liming (CaCO_3), or sodic soils can promote antagonism and affect nutrient absorption. More common antagonisms are between K and Ca, and Mg and Ca (Marschner 1995). Ratios can be misinterpreted since the same ratios can be expected with adequate, excess, or low levels; however, in general, $\text{Ca} > \text{Mg} > \text{K}$ should be maintained.

Additional diagnostic tools can be seen in Appendix A. Other Diagnostic Tools.

4. Fertilize Trees Based on Nutrient Demand Minus Supply

The fertilization dose can be calculated as the demand of the tree minus the supply from the soil, water, or other sources (Equation 1).

Equation 1. Dose = (Demand - Supply)

For N, due to its dynamic nature in the soil-plant system and considering that not everything that is applied is absorbed by the plant, the dose should be adjusted by dividing the calculated amount by the percent efficiency estimated for the block.

Demand

Nutrient demand corresponds to the amount of nutrients that the tree needs for growth and fruit production, including the allocation to fruits, leaf, shoots, roots, and permanent wood. By quantifying these nutrient allocations, it has been possible to determine the total demand for different tree fruit crops. For example, Cheng and Raba (2009) calculated nutrient

Table 2. Tree fruit demand for primary macronutrients per ton of fruit harvested.

Crop	lb N/ton	lb P/ton	lb K/ton	References
Apple (Red)	1.9–2.2	0.4	3.6–4.7	Cheng and Raba 2009; Palmer and Dryden 2006; Silva and Rodríguez 1995
Apple (Green)	3.1	0.4	4.2	Silva and Rodríguez 1995
Apricot	8.3–11	1.3	8.1	Silva and Rodríguez 1995; Weinbaum et al. 1992
Cherry	8.8–12	1.5	9.4	Silva and Rodríguez 1995; Nielsen et al. 2007; Fallahi et al. 2001b
Peach	4.5–12	1.2	9.9	Silva and Rodríguez 1995; Weinbaum et al. 1992
Pear	1.3–2.7	0.6	3.7	Silva and Rodríguez 1995

Use the lower end of the range in mature orchards with small amounts of pruning and where pruning material is recycled. Consider higher ends of the range in weak sites, limited areas, and when leaf N shows deficiency.

requirement as a function of fruit yield (bushel/acre) based on the nutrient requirement obtained in their study, assuming that the ratio between net accumulation of each nutrient in the whole tree from budbreak to fruit harvest and its amount in fruit remains constant across the range of fruit yield (Figure 1).

Macronutrients (lbs/acre)						
Fruit yield (b/a)	N	P	K	Ca	Mg	S
500	22.1	3.7	40.2	15.9	4.9	1.8
750	33.2	5.5	60.2	23.9	7.3	2.7
1000	44.3	7.4	80.3	31.8	9.8	3.6
1250	55.4	9.2	100.4	39.8	12.2	4.5
1500	66.4	11.1	120.5	47.7	14.7	5.4
1750	77.5	12.9	140.6	55.7	17.1	6.3
Micronutrients (grams/acre)						
Fruit yield (b/a)	B	Zn	Cu	Mn	Fe	
500	47.5	30.9	23.6	93.7	75.4	
750	71.2	46.4	35.4	140.6	113.1	
1000	95.0	61.8	47.2	187.4	150.9	
1250	118.7	77.3	59.0	234.3	188.6	
1500	142.5	92.7	70.8	281.1	226.3	
1750	166.2	108.2	82.5	328.0	264.0	

Figure 1. Nutrient requirements as a function of fruit yield for dwarf trees Gala/M9 (Cheng and Raba 2009).

In apples and other tree fruit species, the fruit and new shoots account for more than 90% of total N demand (Cheng and Raba 2009; Silva and Rodríguez 1995). For P and K, the partitioning is mostly to the fruit and secondarily to the leaf, representing more than 75% of the nutrient demand (Silva and Rodríguez 1995). Assuming leaves and pruning material are recycled in the orchard, fruit extraction generally correlates well with nutrient demand in established orchards. The following table summarizes nutrient demand reported by different authors, for different tree fruit, based on fruit extraction and tree growth in well equilibrated orchards (Table 2).

For P and K, due to their recycling process and mobility, the dose can be calculated directly with the demand (Dose = Demand) when levels in the soil are adequate.

For micronutrients (Cu, Zn, S, Mn, Fe, and B) the requirements are very small (grams per acre) and normally foliar fertilization is best when leaf analysis or visual symptoms indicate (note: annually for Zn and B). However, it is important to keep adequate levels in the soil as some nutrients are required in the root zone for growth development and signaling (see sidebar *Calculating Demand Based on Production* for more details).

Calculating Demand Based on Production

Example 1

Apple production of 80 bin/acre = 37 ton/acre.

N demand:

Based on Table 3; 37 tons \times (1.9 to 2.2 lb of N) = 70 to 80 lb/acre.

37 tons \times 0.4 lb of P = 15 lb/acre.

37 tons \times (3.6 to 4.7 lb of K) = 133 to 174 lb/acre.

Cover crops and weeds will also have nutrient demands.

Once the demand is estimated, the next step is to determine how much the soil or other sources can supply.

Supply

Soil mineralization, nutrients in irrigation water, and soil amendments will deliver nutrients to the soil-plant system and should be accounted for and subtracted from the demand.

Phosphorus. P in soils is generally bound to soil particles. The weathering of rocks causes the release of phosphate ions which are distributed in soils and water. Soil pH affects P availability, thus, any change in soil pH could lead to changes in P availability. Soil tests have the goal of estimating the amount of P available for the plant. P-Olsen is recommended for mildly alkaline to alkaline soils. The method relies on “replacement” where soil levels are brought up to the optimum range (15–40 mg/kg) and fertilizer is applied according to the plant demand (Table 2).

Potassium. In soils, K is in three forms: mineral, exchangeable, and soluble K. Mineral K, contained in feldspars and micas, are only available very slowly over time as the minerals weather. Exchangeable K is adsorbed between the layers of clay minerals and is in equilibrium with soluble K. Laboratory soil tests of extractable or available K measure both the exchangeable and soluble portion of K in soils. The recommended management method here relies on “replacement,” where soil levels are brought up to the optimum range (150–250 mg/kg) and fertilizer is applied according to the plant demand (Table 2).

Nitrogen (N). The organic matter (OM) of the soil will deliver N throughout the process of mineralization, and its level in the soil is a good indicator of N availability. OM can supply an average of 20 pounds of available N per year per percent organic matter. Soils in central Washington generally have low levels of OM (1.0–2.0%) which may supply only nominal levels of N. If your soils accumulate organic matter above 1% consider accounting for N derived from mineralized organic matter. *Keep in mind mineralization rates vary by moisture, temperature, and biological activity and are only estimates.* It is important to recognize that some soil tests report organic carbon and others organic matter. Organic matter is a calculated value based on the total organic carbon. Organic matter (%) = total organic carbon (%) \times 1.72.

Nitrogen from compost and manure applications will also be available slowly over time. Depending on soil temperatures, soil moisture, and the C:N of the material, 5% to 30% of the N in a compost or manure application is available per year.

Mineralization rates should be considered after the first and second year, following manure application. After that time, N is tied up in organic matter, but OM levels can still be used to calculate availability. Compost and manure also supply large amounts of P, K, and other nutrients, but these levels will be accounted for in any soil tests taken *after* application. (For more details see [Compost Considerations](#).)

Irrigation water considerations. Irrigation water is the largest input for central Washington orchards each season. Water contains varying amounts of different minerals, depending on the source (e.g., river water, tailwater, well water). Even when present in water at a low concentration, large amounts of minerals (some of which are important plant nutrients) can be added over the course of a season or multiple years. Accounting for the addition of nutrients in irrigation water can lead to better fertility analysis and management. Test irrigation water to know what you are adding. Tests at different times of the season may be needed if changes to water quality are suspected or if a different source is used. Since soil nutrition is based on soluble forms of nutrients, the quality of the irrigation water has the potential to influence nutrient availability. In areas with elevated nitrates in groundwater or canal irrigation water, the N addition from well water can be important and lead to a reduction in applied fertilizer N. Irrigation water with high levels of certain compounds, such as carbonates, may tie up desirable nutrients, like P, and can affect soil pH (Grattan 2002; Ayers and Westcot 1985).

Irrigation water quality in central Washington varies greatly depending on the source. A standard laboratory analysis can give the amount of N as NO₃-N per liter or parts per million (ppm). For example, if you have 5 mg/L of NO₃-N (5 ppm) and you irrigate with 35 in/acre/yr, the amount of N supplied in the season is 40 lb/acre. (See sidebar *Nitrogen Requirement, Subtracting Soil and Water Supply* for more information.)

Nitrogen Requirement, Subtracting Soil and Water Supply

Example 2

Apple production of 80 bin/acre = 37 ton/acre.

Soil OM = 1.0% = 20 lb N.

Water supply = 35 in/acre/season (1 in/acre \approx 103,000 L/acre).

Water analyses = NO₃-N = 1 ppm or mg/L (1 mg/L of water = 0.23 lb/in of water).

Then 1 ppm = (1 ppm \times 0.23 \times 35 inches) = 8 lb of NO₃-N/acre/season.

Total supply = 28 lb of N.

N requirements: 75 lb of N/acre - 28 lb of N supplied = 47 lb of N/acre.

Efficiency

Efficiency corresponds to the percentage of nutrient the plant uses in relation to the total amount applied. Nitrogen can be lost due to denitrification, leaching, volatilization, and immobilization (Sato and Morgan 2008). The magnitude of these losses will vary. For example, in deep, sandy soils with excessive drainage, leaching could account for the bigger proportion of losses, while in a heavy soil with poor drainage and excess of water, denitrification could become the main way to lose N.

For example, in western orchards Neilsen and Neilsen (2002) reported low N use efficiency of less than 30% in a newly planted, high-density apple orchard (less than six years old) on Malling 9 rootstock.

Efficiency is influenced by many different factors, and the percentage can vary under different orchard conditions. In addition to the irrigation and soil type, the method of application, source, timing of application, weed or cover crop demands and competition, root development, and many other factor will determine N efficiency. Good irrigation water management is essential to good N management. The following table is a general estimation of efficiencies under different conditions (Table 3). (See sidebar *Nitrogen Requirement Applying Different Efficiency Levels* for more information.)

Generally, efficiency is considered only for N due to its complex cycle and mobility. Other major and minor nutrients are held within the cation exchange capacity of soils and not easily lost.

Table 3. Estimated nitrogen efficiency under different soil and irrigation systems.

Condition	Estimated N Efficiency
Fertigation, loamy soils, good drainage, healthy roots. Max efficiency.	> 70%
Loamy soils, good drainage, well irrigated.	60%
Sandy soils, over-irrigated soils.	50%
Sandy soils, coarse soils, excessive drainage, compaction, sick trees, excess nutrient status, or other limitations.	< 40%

Nitrogen Requirement Applying Different Efficiency Levels

Example 3

Apple production of 80 bins per acre = 37 tons per acre.

N demand: 75 lb/acre - 28 lb of N (from OM and water) = 47 lb of N/acre.

Fertigation - Well irrigated - Loamy soil

Assume 70% efficiency

Dose = 47 lb of N/acre \div 70/100

Final Dose = 67 lb/acre

Sandy soil with excess drainage. Long hours of irrigation per week.

Assume 40% efficiency

Dose = 47 lb of N/acre \div 40/100

Final Dose = 118 lb/acre

5. Monitoring Nutrient Management Program

Once the fertilization program has been developed, nutrient absorption should be verified and monitored on an annual basis. Plant tissue analysis is used to directly measure the amount of nutrients in the trees. For established perennial crops, it is a good indicator of nutrient status (Marschner 1995). For correct interpretation of results, it is important to follow the recommended sampling procedure. For most species, results have been calibrated for samples of leaf that have recently reach maturity, which normally correspond to mid-season leaf growth, from mid-July to mid-August. At this time of the season, the elements are more stable while maintaining good predictability.

For crops with longer growing periods, like apples and pears, foliar nutrient analysis can alert growers of nutrient deficiencies or toxicities before they are visible, when corrective action can still be made and before yield or fruit quality are reduced.

Leaf analysis can also be used as a tool to diagnose problems outside of the standard recommended period of sampling by collecting samples from abnormal trees and comparing them with healthy ones. In this case, it is important to collect leaves of equivalent branches; vigor, length, height, and age. (For more details see [Leaf Tissue Analysis](#) [Sallato 2018].)

Tissue Analysis Levels

Table 4 provides guidance for leaf analysis interpretation. As indicated above, tree leaf nutritional status changes over the course of the year, thus, leaf analysis interpretation levels will vary if sampling is not conducted in the more stable mid-July through mid-August period.

In central Washington orchards, tissue testing is most useful to determine status of N, K, Ca, Cu, and Zn.

Remember that leaf samples can be contaminated by fungicides (those containing Cu, Zn, etc.), foliar nutrient applications (i.e., Ca), and nutrient-containing dust. Samples should not be taken within 15 days of an application containing nutritional elements, and caution should be taken with those interpretations.

Table 4. Target nutritional ranges used to interpret leaf analysis values for tree fruit^a.

Nutrient	Unit DW	Apple ^{b,d}	Pear ^{b,d}	Cherry ^c	Peach ^c	Apricots ^{b,c}
Nitrogen (N)	%	1.7–2.5	1.8–2.6	2.00–3.03	2.7–3.5	2.4–3.3
Phosphorous (P)	%	0.15–0.3	0.12–0.25	0.10–0.27	0.1–0.30	0.1–0.3
Potassium (K)	%	1.2–1.9	1.0–2.0	1.20–3.3	1.2–3.0	2.0–3.5
Calcium (Ca)	%	1.5–2.0	1.0–3.7	1.20–2.37	1.0–2.5	1.10–4.00
Magnesium (Mg)	%	0.25–0.35	0.25–0.90	0.30–0.77	0.25–0.50	0.25–0.80
Sulfur (S)	%	0.01–0.10	0.01–0.03	0.20–0.40	0.2–0.4	0.20–0.40
Copper (Cu)	mg/kg	5–12	6–20	0–16	4–16	4–16
Zinc (Zn)	mg/kg	15–200	20–60	12–50	20–50	16–50
Manganese (Mn)	mg/kg	25–150	20–170	17–160	20–200	20–160
Iron (Fe)	mg/kg	60–120	100–800	57–250	120–200	60–250
Boron (B)	mg/kg	20–60	20–60	17–60	20–80	20–70

Based on July and August sampling of mature leaves^a. Adapted from Shear and Faust (1980)^b, Reuter and Robinson (1997)^c, Righetti et al. (1990), Silva and Rodríguez (1995)^d.

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The range of recommended levels have not changed significantly throughout the years, despite the changes in cultivars, rootstocks, and orchard systems (Shear and Faust 1980; Righetti et al. 1990; Silva and Rodríguez 1995; Reuter and Robinson 1997; Marschner 1995; Fallahi et al. 2001a; Fallahi et al. 2001b; Cheng and Raba 2009; Palmer and Dryden 2006). The recommended values of nutrient concentrations on leaf tissue has been summarized in Table 4. Determining the adequate level under local conditions can be accomplished with an integrated analysis utilizing the described tools.

If soils levels are adequate and the leaf analyses are below the standards, then:

- (1) Verify possible absorption problems as root development, lack or excess of water, or biotic and abiotic limitations.
- (2) Correct the fertilization dose by adjusting the efficiency or demand (higher value of the demand range).
- (3) In some cases, foliar applications can be considered depending on the element and limiting factor.

Low levels of nutrients in the leaf does not always mean low content in the soil or that it is necessary to apply greater amounts. Understanding the scopes, limitations, and utility of the soils and tissue analyses will secure a correct interpretation of these tools.

Appendix A. Other Diagnostic Tools

- SPAD meter. A portable hand-held device that rapidly estimates leaf chlorophyll content, which is correlated with leaf nitrogen. Neilsen et al. (2017, p. 254) have a nice table on SPAD correlations for different apple cultivars. Use for leaves.
- Cardy meter. A portable nitrate meter (not for in-field use, but can be used on farm). Need to extract nitrate from leaf or soil first.
- X-ray fluorimeter. A non-destructive instrument that can read nutrient levels in leaves and fruit (e.g., Tracer 5, [Bruker Mfg.](#), Kennewick, WA). It may be useful on all elements in the periodic table from magnesium to uranium, which excludes nitrogen and boron. It is possible to do repeated measurements on growing fruit over time.
- Remote sensing. Various soil and vegetation data can be collected from aerial images (airplane, drone) that relate to soil organic matter, water content, and plant vigor. Other tools, such as EC mappers, can also help characterize site soil variability and the properties involved.
- Sap analysis. Some growers are experimenting with sap analysis (sap “squeezed” from fresh leaves), looking at old and new leaves on the same shoot to estimate more real-time nutrient status in the trees during the growing season. This method has been used extensively in greenhouse vegetables, but the data for correlation to tree fruit are generally lacking.

Additional Resources

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