Tree Nutrition and Fertilization
Practical Considerations

By Les P. Werner

CEU LEARNING OBJECTIVES

The arborist will be able to

- define essential elements, discuss the means in which trees acquire essential elements, and discuss the unique characteristics of macronutrients
- explain how various tree factors affect the need for and use of essential elements
- describe the influence that different soil conditions have on the supply and uptake of essential elements
- discuss the role nutrient management plays in ensuring a tree's essential element supply is not reduced by other tree care practices

CEUs for this article apply to Certified Arborist, Utility Specialist, Municipal Specialist, Tree/Worker Climber, and the BCMA practice category.

The complete or partial removal of topsoil during landscape development, changes to the soil's physical, chemical, and biological properties resulting from urbanization, and subsequent management practices, create a soil environment for trees that is remarkably different from that experienced by forest trees. From a tree's perspective, the net effects are small annual growth increments, shortened tree life, and/or a reduced resiliency to water stress and pressures from insects and diseases. Historically, fertilizers have been used to offset the soils reduced nutrient supplying power resulting from these actions.

Fertilization is a management prescription. To be effective the prescription must incorporate information about the tree's nutritional status, its annual needs, the soil's ability to meet these needs, and past/current landscape management activities that could affect either the tree's demand for essential elements or the soil's ability to supply resources. Generically, the fertilizer prescription can be expressed as an equation:

Prescription =
Tree Factors + Soil Factors + Management Factors

Depending upon species, trees require 16–19 essential elements (Table 1). An element is essential if it is involved in metabolic processes, its role cannot be assumed by another element, and the tree requires it to complete its life cycle. Of the essential elements, carbon (C), hydrogen (H), and oxygen (O) account for more than 90 percent of the tree's weight, while the remaining essential elements constitute less than 10 percent. Essential elements come from four sources: atmosphere, water, minerals, and organic. Carbon, hydrogen, and oxygen are acquired by the tree from the atmosphere (CO_2) and water (H_2O) and are collectively used to produce the tree's building block, glucose ($C_6H_{12}O_6$), through the process of photosynthesis.

The other essential elements are derived from the soil. Soil is a collective term representing different sources: elements derived from the weathering of primary minerals, elements released during the decomposition of organic litter, elements dissolved in rainwater, and elements contained in particles deposited on the surface.

Of the EE's, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) accumulate in large quantities within tree tissues. These elements are termed macronutrients and are typically expressed as a

Table 1. Essential Mineral Elements. Derived from *Plant Analysis Handbook II* (Mills and Jones 1996).

Element	Symbol	Source	Sufficiency Range	Mobility	Symptom	Soluble Form
Nitrogen	N	Organic Matter, Atmospheric	1%–6%	M	Older Tissues	NO_3^-, NH_4^+
Phosphorus	P	Ca-phosphate, Organic Matter	0.2%–0.5 %	M	Older Tissues	HPO_3^{2-}, $H_2PO_4^-$
Potassium	K	Primary Minerals, Clays	1.5%–4%	M	Older Tissues	K^+
Calcium	Ca	Sedimentary Rock	0.5%–1.5 %	I	New Tissues	Ca^{2+}
Magnesium	Mg	Primary Minerals	0.15%–0.40 %	M	Older Tissues	Mg^{2+}
Sulfur	S	Organic Matter, Atmospheric	0.15%–0.5 %	M	Older Tissues	SO_4^{2-}
Iron	Fe	Primary Minerals	50–75 ppm	I	New Tissues	$Fe(OH)^{2+}$, Fe^{2+}, Fe^{3+}
Manganese	Mn	Primary Minerals	10–200 ppm	I	New Tissues	Mn^{2+}
Zinc	Zn	Sulfide Minerals	5–10 ppm	I	New Tissues	Zn^+
Molybdenum	Mo	Molybdenite sulfides	0.15–0.30 ppm	I	New Tissues	Mo^+
Copper	Cu	Adsorbed Copper	3–7 ppm	I	New Tissues	Cu^+
Chlorine	Cl	Primary Minerals	50–200 ppm	*	Rare - Toxicity	Cl^-
Boron	B	Primary Minerals	~ 20 ppm	I-M	New Tissues	H_3BO_3

BRYAN KOTWICA, BUGWOOD.ORG

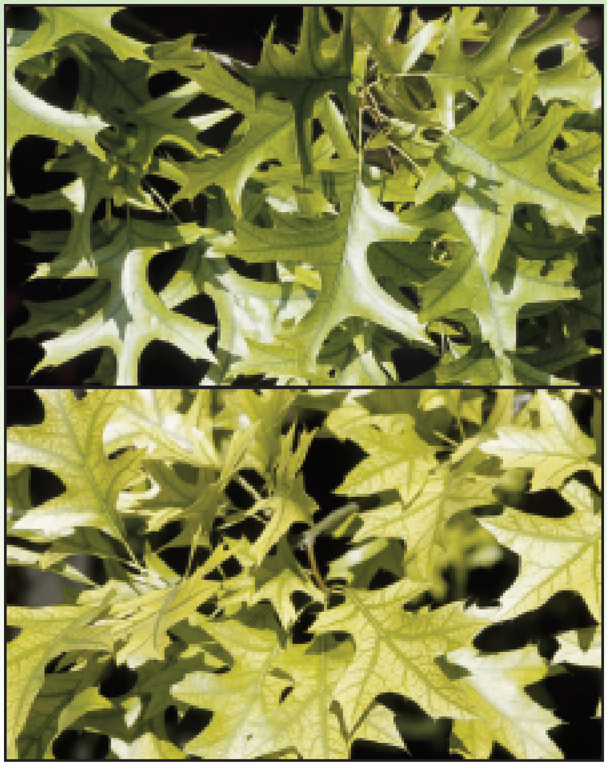
Trees acquire essential elements. Some elements, most notably nitrogen (N), phosphorus (P), and potassium (K), are mobile within trees.

percentage of tissue dry weight in plant analysis reports. Generally, there is a high annual demand for macronutrients. Of the macronutrients, N most commonly limits tree growth. Nitrogen differs from other soil derived essential elements in that it is derived almost exclusively from the decomposition of organic matter, atmospheric deposition, and in some trees, through symbiotic relationships with bacteria capable of acquiring N directly from the atmosphere (N fixation). The remaining essential elements accumulate to lesser degrees within tree tissues and are called secondary nutrients or micronutrients. In plant analysis reports, micronutrients are expressed in parts per million (ppm).

Trees acquire essential elements dissolved in water. Elements dissolved in water exist in an ionic form, meaning they possess a charge. Elements with a positive charge (e.g., K^+) are termed cations, while those with a negative charge (e.g., Cl^-) are called anions. With notable exceptions (e.g., phosphorus, sulfur), the majority of essential elements are taken up as a cation. Nitrogen is unique in that it can be taken up as either a cation (ammonium, NH_4^+) or an anion (nitrate, NO_3^-). The type of charge (cation or anion) and the amount of charge (e.g., $^{2+}$ or $^{3+}$) is governed by the chemical, physical, and biological environment of the soil.

Typically, the concentration of charges/ions in soil water is less than the concentration of charges/ions within the cells of absorbing roots. Consequently, the uptake of charged essential elements often requires metabolic energy to overcome concentration differences. Within the rhizosphere (the area of soil/water just outside an absorbing root) microorganisms (e.g., bacteria, fungi) accumulate in great numbers and facilitate the transfer, release, and uptake of many essential elements. Certain fungi, known as mycorrhizal fungi, often form a symbiotic relationship with tree roots. Mycorrhizal fungi enhance the tree's capacity to acquire water and essential elements. In return, the tree provides the fungi with a useable form of carbon (fungi are not photosynthetic). There is increasing evidence suggesting mycorrhizae have the capacity to acquire organic forms of essential elements, particularly N.

Some elements, most notably N, P, and K, are mobile within the tree (Note: this discussion is not referring to essential element mobility within the soil). The typical pattern of movement for mobile elements is from tissues that are not actively growing, to tissues that are actively growing. Symptoms for deficiencies of mobile elements (e.g., K) are evident in older tissues. Other elements, such as calcium (Ca) and iron (Fe), become immobile once they have been incorporated into tree tissues. Symptoms for deficiencies of immobile elements (e.g., Fe) present themselves in developing tissues. The concentration of essential elements within tree tissues, particularly the foliage, changes over the course of the growing season. For instance, the concentration of N in emerging, immature leaves is much greater than the concentration in mature or senescing leaves. The changes in tissue concentration in this instance are the result of leaf expansion, leaching of soluble N, and N export prior to leaf fall.



JOSEPH O'BRIEN, USDA FOREST SERVICE, BUGWOOD.ORG

The concentration of essential elements within tree tissues, particularly the foliage, changes over the course of the growing season. Symptoms for deficiencies of immobile elements, such as iron, often present themselves in developing tissues. Photo of iron chlorosis in pin oak (*Quercus palustris* Muenchh.).

When the availability of an essential element is so low as to negatively affect tree metabolism and threaten tree survival, the element is said to be deficient. When essential element availability reduces growth rate, but does not cause metabolic dysfunction or premature death, the element is limiting. For example, a tree that developed on a rock outcrop may experience frequent shortages in the availability of resources, yet manages to persist within the environment for the full duration of its genetic life span. The availability of resources in this example, are not resulting in metabolic dysfunction or death, but they are limiting aboveground growth. Interestingly, trees have the capacity to maintain critical concentrations of essential elements (particularly mobile elements) in developing tissues by adjusting the rate of growth. Lastly, an excess of a particular element can also negatively affect tree growth and development. Excesses of elements can be toxic and/or inhibit the uptake of other essential elements.

Tree Factors

Tree Age

Growth is an irreversible increase in size/mass. Growth tends to be fast (large increases) in juvenile trees, slow (small increases) in mature trees, and stable (negligible increases) in over-mature trees. Consequently, as trees age their total biomass has a tendency to increase. However, not all accumulated tissues within a mature tree are alive or functioning at the same metabolic rate. Actively growing tissues have a high demand for essential elements; senescing tissues have a low demand for essential elements. Remarkably, the tree recognizes and uses this demand gradient to its advantage. Resources within low-demand tissues are used to supplement resource needs in high-demand tissues.

For example, during heartwood formation, or prior to leaf shedding, mobile essential elements are removed from these tissues and stored elsewhere in the tree and/or transported to areas with a high demand for essential elements. In the process, trees conserve energy (remember; the acquisition and use of essential elements from soil solution often requires energy), and there is a reduced burden on the soil to supply essential elements (think of the demand for essential elements a mature stand of redwood trees would place on the soil if this were not the case). The increases in biomass which accompany aging translate into a larger account from which resources can be drawn.

Growth Pattern

Tree growth patterns range from a defined period of growth (determinate) to multiple flushes of growth each year (indeterminate). Some trees produce multiple growth flushes when young and progress toward a single growth period when mature. All things being equal (e.g., temperature, soil moisture, room to grow), trees producing multiple flushes of growth have a tendency to accumulate more biomass over the growing season and demonstrate a higher demand for essential elements.

Leaf Retention and Succession Stage

As a general rule, trees that shed their leaves on an annual basis (i.e., deciduous) have a lower nutrient use efficiency (NUE, amount of carbon acquired per unit of essential element), relative to trees that maintain their leaves for more than a single growing season (i.e., evergreens). Similar generalizations can be made about succession stage; early succession stage trees tend to have lower NUE values relative to late succession stage trees. Differences in NUE can be translated into generalized statements of annual demand for EE's. Trees with lower NUE values require more essential elements to produce an equivalent amount of biomass in trees with a higher NUE.

Tree Health

Trees regulate the allocation of the products from photosynthesis to specific tissues (e.g., roots) or functions (e.g., production of defense compounds) based on the availability of resources. Health is a manifestation of how well the tree is coping with the environment. Consequently, the amount of aboveground growth is not necessarily an accurate measure of overall tree health. If the cause of the unhealthy condition is an essential element deficiency, then providing that element through fertilization is a reasonable course of action. If the cause for the unhealthy condition is not a function of nutrient availability, the outcome of fertilization is not as clear.

Soil and Tree Nutrition

Soil consists of minerals, organic matter (OM), and water or air. Collectively, the soil components serve three fundamental roles. First, soil is a source of essential elements. The nutrient-supplying power of soil is related to the type of minerals, the degree to which the minerals have weathered, the amount/quality of organic matter, and the ability to hold onto essential elements released during these processes.

Second, soil holds onto and supplies trees with water. Trees take up essential elements dissolved in water. The degree to which essential elements are taken up is related to the soil's capacity to supply essential elements and water.

Third, soil provides a medium for root anchorage and mechanical support of aboveground tissues.

AARON H. BYNUM, ISA

Growth tends to be fast (large increases) in juvenile trees, slow (small increases) in mature trees, and stable (negligible increases) in over-mature trees. Consequently, as trees age their total biomass has a tendency to increase.

Soil Factors

Cation Exchange Capacity and Base Saturation

Fundamentally, cation exchange sites represent negative charges on either clay particles or organic matter. These negative charges are offset by positively charged cations. The greater the number of negative sites, the higher the CEC. However, CEC does not indicate which cations are present on the exchange sites. Base saturation (%) provides information about the level of Ca, Mg, K, and Na (collectively

DANIEL HERMS, THE OHIO STATE UNIVERSITY, BUGWOOD.ORG

The nutrient-supplying power of soil is related to the type of minerals, the degree to which the minerals have weathered, the amount/quality of organic matter, and the ability to hold onto essential elements released during these processes. Photo of field plots using isolated soil microcosms for a study.

termed base cations) present on the exchange sites. High base saturation values (e.g., >60 percent), indicate an abundance of cations typically required in high amounts by trees.

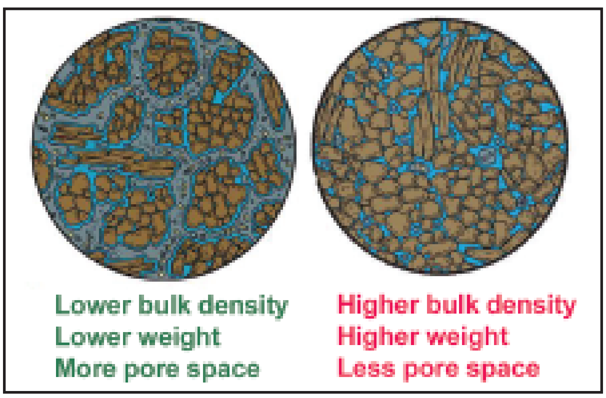
Bulk Density

Soil compaction is a major threat to the long-term survival of trees in urban landscapes. Bulk density (BD, g/cm^3) is a measure of soil compaction. The degree to which a soil compacts is related to texture, soil organic matter content, soil water content, and the frequency/type of traffic. Fine textured soils compact to a greater degree than coarse soils, density decreases with increasing soil organic matter, and wet soils have a tendency to compact to a higher degree than dry soils. Increases in BD reduce water movement into/through the soil and the amount of water the tree can access. Additionally, oxygen levels decrease as BD increases. Reduced oxygen levels adversely affect root growth, development, and function, as both root growth and metabolism require oxygen. At high BD (e.g. ≥ 1.6 g/cm^3) the ability of tree roots to move through the soil may be restricted.

Soil Volume

Trees obtain water and essential elements from the soil. As the volume for a given soil type increases so does the capacity to supply water and essential elements. Minimum soil volumes have been established based upon expected mature tree canopy spread (1–2 ft^3/ft^2) or diameter (50–70 ft^3/inch).

BRYAN KOTWICA, BUGWOOD.ORG



Soil compaction is a major threat to the long-term survival of trees in urban landscapes.

Promoting top growth through improper fertilization and watering in trees with severely restricted soil volumes can increase the trees susceptibility to tipping during wind events.

Textural Class

Soil texture influences CEC, water holding capacity, and the soil atmosphere. Additionally, the soil particle size and the degree of aggregation control water movement into and through the soil. Coarse textured soils (e.g., sand) typically drain more freely than fine textured soils (e.g., clay), and possesses a lower CEC. Water that drains from the soil has the capacity to carry with it essential elements. The removal of elements in soil water is called leaching.

Organic Matter

Roots, leaves, twigs, flowers, fruit, and the remains of organisms that occupy the soil, all contribute organic matter to the soil. Plant organic matter consists of water soluble compounds, cellulose, hemicelluloses, lignin, and waxes, all of which undergo biologically induced reactions that degrade their physical structures and chemical compositions. In the process, essential elements contained in decomposing organic litter are cycled through organisms (e.g., fungi, bacteria) responsible for the breakdown. At the end, a stable organic complex, called humus, remains. Humus represents a long term source of carbon, which is critical to soil micro-organisms, and enhances CEC and water holding capacity.

pH

Soil pH is a measure of the activity of hydrogen (H^+). Soils with a pH below 7.0 are considered acidic and soils with a pH above 7.0 are considered basic. Most essential elements are soluble in water and thus available for uptake, in soils that are slightly acidic. Under very acidic or basic soil conditions certain essential elements form insoluble complexes with other elements, rendering them unavailable for uptake. A substantial amount of the soils cation exchange sites are associated with soil organic matter. Generally, the availability of cation exchange sites increases with rising soil pH.

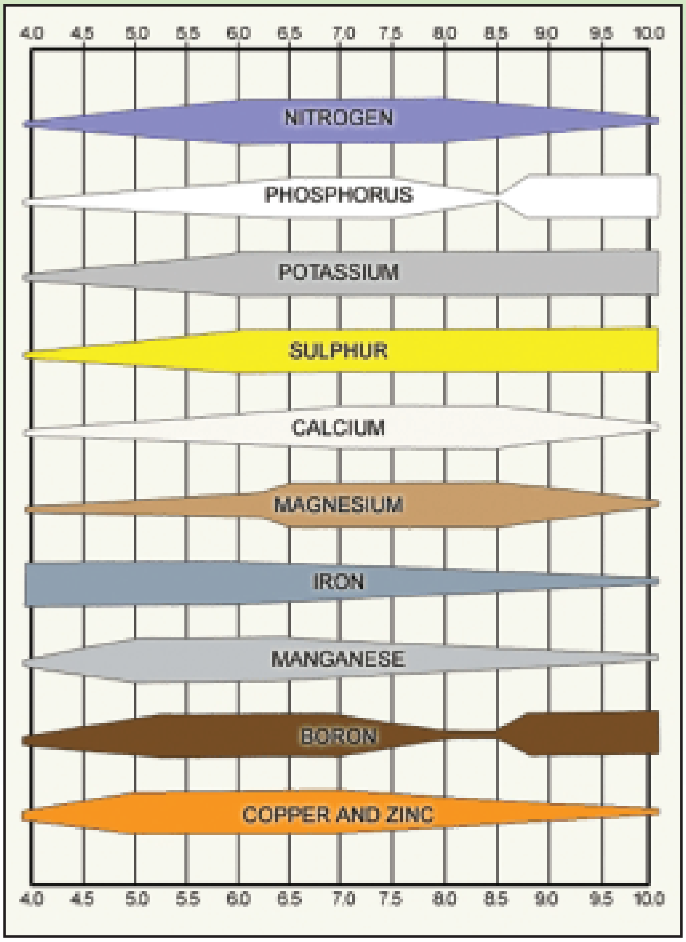
Soil pH also influences the composition/activity of microorganisms. Generally, the activity of fungi increases at lower pH, and the activity of bacteria increase with rising pH.

Salinity

Tests for salinity involve measuring the soil's ability to conduct electricity (EC, mmhos/cm). EC increases with increasing soluble salt concentration. High EC values (>2 mmhos/cm) can retard water uptake, destroy soil structure, and can negatively affect tree growth. The application of deicing salts, improper irrigation, and chronic fertilization can temporarily increase the level of soluble salts in soil.

Biological Properties

Essential elements are made available to the tree through the weathering of primary minerals and the decomposition of organic matter. Over time, organic matter will accumulate in the soil. In temperate forests, the annual addition, accumulation, and breakdown of organic litter regulates tree growth rate. The ability of soil to supply essential elements is directly related to how much organic matter is being added each year, the quality (e.g., chemical composition)



Graph indicates impact of soil pH on essential element solubility.

of the litter being added, and the capacity to decompose organic litter. Soil water content and temperature are also critical factors affecting the rate of litter decomposition and release of essential elements.

Organic matter decomposition is controlled by billions of microscopic bacteria, fungi, insects, earthworms, and mites. The composition and activity of these organisms can be influenced by soil chemistry (e.g., pH) and the physical properties (e.g., organic matter content, bulk density) of the soil. Genetic techniques can be used to describe, to a limited extent, microbial biomass and the composition/ structure of microorganisms within the soil. Unfortunately, our current understanding of what constitutes an ideal biological composition for urban soils is limited. Efforts to improve a soil's biological health have focused on creating a physical environment that will allow the organisms to thrive (i.e., managing soil compaction), supplying organic substrates, and/or introducing microorganisms to build up their populations within the soil (e.g., mycorrhizae, compost teas).

Management Factors

Associated Vegetation

In naturally forested environments, trees grow in association with other trees and a wide variety of understory plants. Comparatively, urban trees are often grown as individuals in association with comparatively uniform, dense understory vegetation (e.g., turf grass, ground covers). Generally, high-density understory vegetation will often compete more effectively for water and essential elements. Under this scenario, the availability of essential elements, specifically N, may limit tree growth. Fertilization should be considered only if an evaluation of the understory fertilization program reveals the current nutrient management program cannot meet the objectives for both the tree(s) and the understory vegetation.

Pesticide Use

The repeated (chronic) use of pesticides can adversely affect the composition and activity of soil microbes. From a nutrient management perspective, several options exist; supply, through fertilization, an appropriate amount of essential elements to maintain the health of the tree, restore the biological health of the soil, and reduce pesticide use.

Organic Litter Removal

Fundamentally, the collection and removal of tree/ understory litter (e.g., leaves, branches) represents a net loss of essential elements from the landscape. The collection and removal of deciduous tree leaf litter eliminates approximately 44–88 lbs nitrogen per acre from the landscape. These values provide a good starting point for discussions surrounding the rate of application for trees in managed urban landscapes.

Irrigation

Surplus soil water moves by gravitational flow through macro-pores and often contains a supply of essential elements. More importantly, frequent, heavy irrigation can remove substantial amounts of essential elements from the root zone. Fertilizer application rates and the type of fertilizer (e.g., fast release) must be adjusted based on the frequency and intensity of irrigation.

The second part of this series will introduce a fertilization matrix to aid in determining the need and extent of fertilization.

Les P. Werner is an associate professor of Urban Forestry with the College of Natural Resources, University of Wisconsin - Stevens Point (Stevens Point, WI).

W. ROBERT MAPLE, USDA FOREST SERVICE, BUGWOOD.ORG

Roots, leaves, twigs, flowers, fruit, and the remains of organisms that occupy the soil all contribute organic matter to the soil. Photo of longleaf pine (*Pinus palustris* P. Mill.) forest understory, Conecuh County, Alabama, U.S.

CEU TEST QUESTIONS

Take your quiz online! Go to www.isa-arbor.com/certification/ceus.aspx and click on "Arborist News Quizzes Online." If you need a login and password, send an e-mail to cert@isa-arbor.com.

To receive continuing education unit (CEU) credit (1.0 CEU) for home study of this article, after you have read it, darken the appropriate circles on the answer form of the insert card in this issue of *Arborist News*. (A photocopy of the answer form is ***not*** acceptable.) A passing score for this test is 16 correct answers.

Next, complete the registration information, ***including your certification number***, on the answer form and send it to ISA, P.O. Box 3129, Champaign, IL 61826-3129. Answer forms for this test, **Tree Nutrition and Fertilization: Practical Considerations**, may be sent for the next 12 months.

If you do not pass the quiz, ISA will send you a retake answer sheet. You may take the quiz as often as necessary to pass. If you pass, you will ***not*** be notified; rather, you will see the credit on your CEU report (available online). Processing CEUs takes 4 to 6 weeks.

CEUs for this article apply to Certified Arborist, Utility Specialist, Municipal Specialist, Tree/Worker Climber, and the BCMA practice category.

1. Macronutrients, elements that accumulate in tree tissue in large amounts, are typically expressed in plant analysis reports as
   a. parts per million
   b. a percentage of tissue dry weight
   c. a probable concentration of charges/ions
   d. an estimated fraction of the tree's biomass
2. Fertilization is a prescription that takes into account which three factors?
   a. tree, soil, management
   b. tree, management, equipment
   c. soil, tree, economic
   d. management, economic, equipment
3. The concentration of cations/anions is typically higher in the soil than in root tissues.
   a. True
   b. False
4. The three elements which make up more than 90 percent of a tree's biomass are:
   a. nitrogen, phosphorus, calcium
   b. carbon, nitrogen, sulfur
   c. carbon, hydrogen, oxygen
   d. nitrogen, hydrogen, oxygen
5. Most essential elements are taken up as
   a. anions
   b. cations
   c. mycorrhizae
   d. none of the above
6. Highly weathered soils typically have lower base saturation levels.
   a. True
   b. False
7. Mobile essential elements typically move
   a. from tissues with high demand to tissues with low demand
   b. from tissues with low demand to tissues with high demand
   c. at a steady rate throughout the tree
   d. in an unpredictable pattern unrelated to tissue demands
8. When the availability of an essential element reduces growth, but does not shorten the life of the tree, the element is considered
   a. deficient
   b. supplementary
   c. ineffective
   d. limiting
9. Soils with a low base saturation will typically have higher levels of available essential elements.
   a. True
   b. False
10. The element which most often limits growth is
   a. carbon
   b. sulfur
   c. nitrogen
   d. iron
11. Which of the following is not a primary source of nitrogen?
   a. primary minerals
   b. atmosphere
   c. organic matter
   d. appropriate fertilization
12. Evergreen trees typically have higher nutrient use efficiencies (amount of biomass produced per unit of resource acquired).
   a. True
   b. False
13. Most essential elements are soluble at a soil pH of
   a. 8.8
   b. 7.8
   c. 6.8
   d. 5.8
14. All elements that accumulate in tree tissue are, by definition, essential.
   a. True
   b. False
15. Which trees have a lower annual demand for essential elements?
   a. trees that retain their leaves for multiple growing seasons
   b. trees that lose all their leaves every year
   c. trees that have multiple growing phases throughout the year
   d. the annual demand for essential elements does not vary from tree to tree
16. Trees supplement their annual demand for essential elements by recycling elements.
   a. True
   b. False
17. Soil texture influences
   a. cation exchange capacity (CEC)
   b. water holding capacity
   c. soil atmosphere
   d. all of the above
18. Increases in soil volume result in
   a. decreased amounts of essential elements and decreased available water
   b. increased amounts of essential elements and decreased available water
   c. decreased amounts of essential elements and increased available water
   d. increased amounts of essential elements and increased available water
19. The concentration of cations/anions is typically higher in the soil than in root tissues.
   a. True
   b. False
20. High soil salt concentrations stimulate water and essential element uptake.
   a. True
   b. False

Tree Nutrition and Fertilization
Practical Considerations (part II)

By Les P. Werner

LEARNING OBJECTIVES

The arborist will be able to

- describe three categories of objectives for tree fertilization
- discuss fertilizer analysis, form, and mode of action
- explain fertilizer application methods
- calculate rates of fertilizer application

CEUs for this article apply to Certified Arborist, Utility Specialist, Municipal Specialist, Tree/Worker Climber, and the BCMA practice category.

In the United States, tree fertilization should comply with the ANSI A300 (Part 2) standards developed by the Accredited Standards Committee on Tree, Shrub, and other Woody Plant Maintenance Operations. These standards are intended for use in preparing specifications for tree maintenance. ISA's *Best Management Practices – Tree and Shrub Fertilization* offers detailed information on how to apply the ANSI A300 standards.

Specifications for tree fertilization should clearly define the objectives. The objectives must take into account the previously discussed tree, soil, and management factors. Typically, the stated objective for fertilization will fall into three broad categories: Correcting a Nutrient Deficiency; Maintenance Fertilization; Growth Promoting Fertilization.

As indicated in the previous article, nutrient deficiencies can result in premature death. Diagnosing and correcting nutrient deficiencies, however, can be tricky business; it requires knowledge of the appropriate levels of essential element(s) within plant tissues and the determination of the underlying causes of the deficiency. Knowledge regarding which element(s) may be responsible for the declining condition may be attained through a combination of soil and tissue analyses, although the interpretation of the results from such analyses requires careful consideration. Table 1 provides a list of the essential elements and a corresponding range of sufficiency values within leaf tissues. Assuming there are no root development restrictions or limitations on the volume of soil, deficiencies can generally be attributed to insufficient amounts of a particular essential element within the mineral component of the soil, to reduced biological activity and/or changes in the composition and structure of microbial populations that release essential elements from organic complexes, or to a chemical environment that renders essential elements insoluble (i.e., pH). From a long-term perspective, management activities should ultimately concentrate on correcting the underlying cause. With this approach, fertilization becomes a secondary management tool within a larger nutrient management plan. If rooting restrictions or soil volume limitations exist, identifying and correcting the cause of the deficiency may be decidedly more complex.

Maintenance fertilization is a low level rate application of fertilizer, the intent being to offset reductions in the source of essential elements resulting from specific landscape management practices. For instance, in many managed landscapes,

Table 1. Essential Mineral Elements. Derived from *Plant Analysis Handbook II* (Mills and Jones 1996).

Element	Symbol	Source	Sufficiency Range	Mobility	Symptom	Soluble Form
Nitrogen	N	Organic Matter, Atmospheric	1%–6%	M	Older Tissues	NO_3^-, NH_4^+
Phosphorus	P	Ca-phosphate, Organic Matter	0.2%–0.5 %	M	Older Tissues	HPO_3^{2-}, $H_2PO_4^-$
Potassium	K	Primary Minerals, Clays	1.5%–4%	M	Older Tissues	K^+
Calcium	Ca	Sedimentary Rock	0.5%–1.5 %	I	New Tissues	Ca^{2+}
Magnesium	Mg	Primary Minerals	0.15%–0.40 %	M	Older Tissues	Mg^{2+}
Sulfur	S	Organic Matter, Atmospheric	0.15%–0.5 %	M	Older Tissues	SO_4^{2-}
Iron	Fe	Primary Minerals	50–75 ppm	I	New Tissues	$Fe(OH)^{2+}$, Fe^{2+}, Fe^{3+}
Manganese	Mn	Primary Minerals	10–200 ppm	I	New Tissues	Mn^{2+}
Zinc	Zn	Sulfide Minerals	5–10 ppm	I	New Tissues	Zn^+
Molybdenum	Mo	Molybdenite sulfides	0.15–0.30 ppm	I	New Tissues	Mo^+
Copper	Cu	Adsorbed Copper	3–7 ppm	I	New Tissues	Cu^+
Chlorine	Cl	Primary Minerals	50–200 ppm	*	Rare - Toxicity	Cl^-
Boron	B	Primary Minerals	~ 20 ppm	I-M	New Tissues	H_3BO_3

CHRIS EVANS, RIVER TO RIVER CWMA, BUGWOOD.ORG

Removal of deciduous tree litter—roots, leaves, twigs, and other forms of organic matter—results in a loss of essential elements released through decomposition.

annual tree litter (leaves, fruit, twigs, and branches) is removed from the site. This removal constitutes a net loss of essential elements that could be released through the decomposition of organic material. Research has demonstrated that the amount of nitrogen removed from the landscape through the collection of deciduous tree leaves is approximately 1 to 1.5 lbs (0.5 to 0.75 kg) of nitrogen per 1000 ft^2 of canopy coverage per year. The low level rates of application associated with maintenance fertilization regime are also most appropriate for newly established trees and very mature trees.

Fundamentally, growth promoting fertilization is the application of a fertilizer at a rate in excess of that used for maintenance fertilization. This objective is most appropriate for young trees in the rapid growth phase. Arborists must be aware that there is still considerable debate regarding the increased susceptibility to insects and diseases that may be associated with stimulating fast growth.

Fertilizer Types

Fertilizers are defined by their chemical composition, form, and mode of action. Understanding these components is crucial to developing an effective and efficient nutrient management program.

Chemical Composition

The chemical composition of a fertilizer is called an analysis. The analysis simply indicates the elements contained in the fertilizer, and the relative proportions (percentage of dry weight) of each element. Complete fertilizers contain the macronutrients nitrogen (N), phosphorus (P), and potassium (K). The analysis for a complete fertilizer, therefore, consists of three numbers (e.g., 10-10-10), each number reflecting the percentage of the dry weight occupied by total N, available phosphoric acid (P_2O_5), and soluble potash (K_2O). The order of the numbers in the analysis remains constant; the percentage of N is always listed first, followed by P and then K.

For example, a complete fertilizer with an analysis of 10-6-4 contains 10 percent N, 6 percent P, and 4 percent K. A 50-lb (23 kg) bag of this fertilizer would, therefore, contain 5 lbs (2.3 kg) of N, 3 lbs (1.4 kg) of P, and 2 lbs (1 kg) of K. The analysis allows for the determination of how much fertilizer should be used to meet the desired objective stated in the nutrient management plan.

For instance, if the nutrient management plan called for 2 lbs (1 kg) of N per 1000 ft^2 of canopy coverage to be applied to the soil around a tree, the arborist must, using the same 10-6-4 fertilizer, put down 20 lbs (10 kg) of fertilizer. By way of explanation, 10 percent of 20 lbs (10 kg) is 2 lbs (1 kg). A quick way to calculate the amount of fertilizer required is to divide the targeted amount for a specific element by the percentage listed in the fertilizer analysis.

Target: 2 lbs (1 kg) of N
Analysis: 10-6-4
Fertilizer Amount: 2 / 0.1 = 20
(Note: 0.1 is the same as 10 percent)

The use of a complete fertilizer to meet the nutrient management objectives must be justified by a soil and/or tissue analysis to support its application. Often, a complete fertilizer is not needed, because there are typically sufficient amounts of P and K in the soil. In many regions of the United States, fertilizers containing P have been severely limited as a result of concern over P contamination in surface bodies of water.

Fertilizer Mode of Action

Fast-Release and Slow-Release

Regardless of the mode of action, the intent of fertilization is to provide essential elements to the tree in a timely

BRIAN KOTWICA

The chemical composition of a fertilizer is called an analysis. The analysis simply indicates the elements contained in the fertilizer, and the relative proportions (percentage of dry weight) of each element.

►

CONTINUING EDUCATION UNIT

manner; in other words, to make the essential elements available when the tree can use them. Fertilizers can be categorized based on how quickly the essential elements become soluble in water. In fast-release fertilizers, the essential elements are soluble immediately after their placement in the landscape. Conversely, essential elements in slow-release fertilizers become soluble over time.

The release of essential elements in slow-release fertilizers are generally brought about through one of three mechanisms: biological decomposition of the fertilizer, hydration (water dissolves the fertilizer), or heat. The latter of these is usually associated with granular fertilizers that have been coated with either a resin or sulfur. Fundamentally, fertilizers are salts. Very high concentrations of salts within the soil can negatively affect water uptake, resulting in what appears to be burning of the foliage. Slow-release fertilizers generally have a lower burn potential than fast-release fertilizers. Consequently, slow-release fertilizers *may* be applied at a higher rate, resulting in fewer applications. All fertilizers can leach through the soil profile and into the groundwater if the application is mistimed relative to demand. However, fast-release fertilizers are more prone to leaching losses than slow-release fertilizers.

Fertilizer Form

Organic and Inorganic Fertilizers

Chemically, an organic fertilizer is one that contains carbon. However, many synthetic fertilizers also contain C (urea and urea formaldehyde are examples of manufactured/synthetic organic fertilizers). Consequently, organic fertilizers are recognized as having been derived from once-living organisms. Examples of organic fertilizers are manure, treated sewage, fish meal, bat guano, and compost. Organic fertilizers typically contain smaller amounts of essential elements that are released slowly. Conversely, inorganic fertilizers are manufactured combinations of minerals and essential elements. Typically, inorganic fertilizers possess a higher concentration of essential elements, which may be formulated to be either fast release or slow release. Both forms of fertilizer are available in either liquid or dry formulations.

Fertilizer Application Methods

Generally, there are four recognized methods of delivering the fertilizer to a tree: broadcast applications, sub-surface applications, trunk injection, and foliar applications.

Broadcast

In the broadcast application method, fertilizer is delivered to the surface of the soil. The fertilizer may be in either a liquid or dry form. The fertilizer is typically distributed evenly over as much of the rooting zone as possible. This application method is particularly effective for open grown trees with little or no vegetative understory. When the understory vegetation is dense (e.g., turf grass), much of the fertilizer may be captured by the competing vegetation.

Sub-surface

In the sub-surface application method, fertilizer is applied 6 to 12 inches (15-30 cm) beneath the soil surface in either a liquid or dry formulation. This method is typically employed when there is a high density of competing understory vegetation. The rationale behind this method of application is to place the fertilizer at a depth that will most benefit the tree and not the understory vegetation. Individual application sites are typically arranged in a grid (e.g., 2 ft x 2 ft; 1 m x 1 m) beneath the crown of the tree, with the total fertilizer dose being divided equally amongst the individual application sites.

Trunk Injection

Trunk injections or capsule implants are most often used to correct micronutrient deficiencies (e.g., iron induced chlorosis); typically, injections are not a viable method for the delivery of macronutrients. The technique requires the insertion of a low volume of product directly into the vascular system (i.e., xylem) of the tree. The injection sites are spaced at fixed intervals [e.g., every six inches (15 cm)], around the circumference of the tree at the root flare. The major disadvantage of this delivery system is that it wounds the tree; therefore, it is not a recommended annual treatment.

The sub-surface application method, fertilizer is applied 6 to 12 inches (15-30 cm) beneath the soil surface in either a liquid or dry formulation.

Foliar

Foliar fertilization should only be considered if the soil chemistry, most notably soil pH, indicates that most essential elements are not in a soluble form and there has been limited success with the application of soil-based fertilizers. In this method, fertilizers are sprayed, in a liquid form, onto the leaf surface. The physical makeup of the leaf requires foliar fertilizers consist almost exclusively of readily soluble (i.e., fast-release) fertilizers. Water insoluble fertilizers do not readily move through the pores in the cuticle of a leaf—and there are many waxes and oils on the leaf surface that inhibit uptake. The effectiveness of this application method is largely determined by the formulation of the fertilizer and how long the fertilizer water stays on the leaf surface. To date, the most successful applications have focused on supplementing calcium, potassium, iron, or zinc.

DAVID CAPPAERT, MICHIGAN STATE UNIVERSITY, BUGWOOD.ORG

Trunk injections or capsule implants are most often used to correct micronutrient deficiencies, such as chlorosis. Typically, injections are not a viable method for the delivery of macronutrients. Photo demonstrates application of Mauget Generation II capsules, for trunk injection of ash (*Fraxinus* spp.).

Rate of Application

The rate of application is first and foremost a tree management prescription. This prescription is based on achieving a desired objective that is to be identified prior to the application of a fertilizer. Currently, the ANSI A300 standards recommend that annual application rates do not exceed 3 lbs (1.4 kg) of nitrogen per 1000 ft^2 (93 m^2) for fast-release fertilizers, or 6 lbs (2.7 kg) of nitrogen per 1000 ft^2 (93 m^2) for slow-release fertilizers. These values represent the upper limits for an annual rate of application whose objective is to promote growth. Based on available research, the upper limit for maintenance fertilization appears to be 2 lbs (0.9 kg) of nitrogen per 1000 ft^2 (93 m^2). Keep in mind these values represent the best case scenario with respect to various tree, soil, and management factors.

The baseline annual rates of application, according to the management objectives, are:

Maintenance Fertilization: 1 lb (0.5 kg) per 1000 ft^2 (93 m^2)

Growth Promoting Fertilization: 2 lbs (1.4 kg) per 1000 ft^2 (93 m^2)

These values represent the mid-point in the fertilization range based on fertility research aimed at promoting growth in trees, and research examining nitrogen losses associated with tree litter removal. They also represent the starting point for determining the rate of application. Adjustments, either up or down, to this rate of application are made based on an evaluation of the tree, soil, and management factors.

E. THOMAS SMILEY

Micronutrient deficiencies can result in chlorosis, as with *Gingko biloba* here.

Tree, Soil, Management Factor Adjustments

Table 2 provides a draft of a decision matrix that helps determine the direction of adjustments to the aforementioned baseline rates of application. The direction of adjustment takes into account tree, soil, and management factors. (Point values within the matrix are examples, they are not intended to be universal, but rather provide a framework upon which to develop a local decision matrix.)

How to use the table:

1. Calculate point values for each of the adjustment factor categories.
2. Sum the values of the respective adjustment factor categories.
3. Read the Total Point Recommendations to determine the direction of adjustment to the baseline rate of application.

Please Note: the table does *not* provide information regarding how big or small the adjustment to the baseline rate of application should be. The magnitude of adjustment, therefore, requires knowledge of local research. Keep in mind that each fertilization objective has a maximum rate of application stated in the ANSI A300 Standards for Tree Maintenance Operations.

Determination of Application Amounts

The amount of fertilizer to be placed within the landscape is a function of the fertilizer analysis, the rate of application, and the area of the landscape to be fertilized. For example:

Fertilizer Analysis: 16-4-4
Area to be fertilized: 2000 ft^2 (186 m^2)
Rate of application: 2 lbs (0.9 kg) of N per 1000 ft^2 (93 m^2)

Total Amount of nitrogen to be applied: $2 \times 2 = 4$ lbs (1.8 kg)
Total amount of fertilizer to be applied: $4 \div 0.16 = 25$ lbs (11.3 kg)

(Reminder: 16 percent is the same as 0.16.)

The fertilizer should be placed evenly across the entire landscape regardless of the application method (e.g., broadcast or sub-surface).

►

CONTINUING EDUCATION UNIT

Table 2. Example of how Tree, Soil, and Management factors may be used to adjust the baseline rate of application for tree fertilization. The baseline rate for promoting growth is 2 lbs (0.9 kg) of N per 1000 ft² (100 m²). The baseline rate for maintenance fertilization is 1 lb (0.5 kg) of N per 1000 ft² (100 m²).

Tree Factors

Factor	Type	Points
Age	Transplant	0
	Young	2
	Mature	1
Health	Declining	0[z]
	Healthy	2
Species	Coniferous	1
	Deciduous	2
Growth Pattern	Determinate	1
	In-determinate	2

[z] This value could be 1, if the cause for the tree declining may be partially attributed to the availability of essential elements.

Soil Factors

Factor	Type	Points
Soil Organic Matter	Low (< 3%)	2
	Medium (3%-5 %)	1
	High (> 5%)	0
pH	Alkaline (> 7.5)	0
	Neutral (6.5-7.5)	1
	Acidic (<6.5)	2
Cation Exchange Capacity	Low (< 15 cmol/kg)	2
	Medium (15-20 cmol/kg)	1
	High (> 20 cmol/kg)	0
Base Saturation	Low (< 40%)	2
	Medium (40%-60%)	1
	High (> 60%)	0
Soil Texture	Fine	2
	Medium	1
	Coarse	0
Soil Volume	< 2 ft^3 soil per ft^2 canopy	1
	> 2 ft^3 soil per ft^2 canopy	2

Management Factors

Factor	Type	Points
Turf Fertilization	Yes	1
	No	2
Supplemental Irrigation	Yes	2
	No	1
Pesticides Applied	Yes	2
	No	1
Organic Litter Removed	Yes	2
	No	1

Tree Factor Total: _________

Soil Factor Total: _________

Management Factor Total: _________

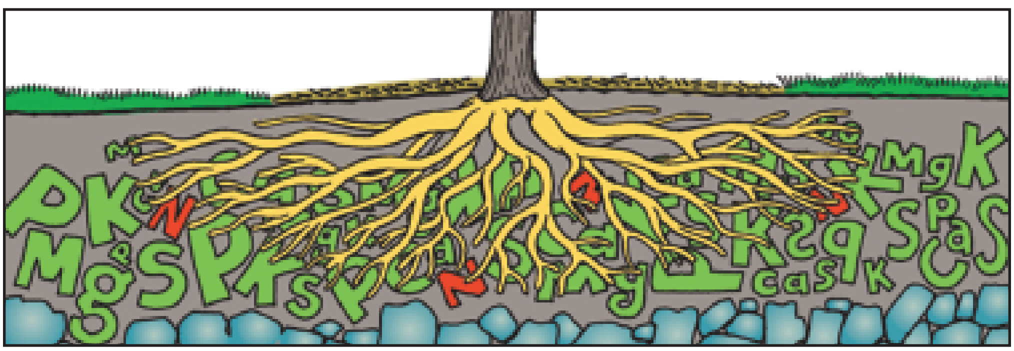
Total Points	Fertilizer Recommendation
22 – 28	Increase baseline rate of application
15 – 21	Maintain baseline rate of application
< 15	Decrease baseline rate of application

Timing of Application

Fertilizers should be applied when the tree can use it. Uptake from the soil is at its highest during the active growing season and when soil moisture is abundant. From a biological perspective, trees will typically rely on stored reserves of the mobile macronutrients to meet the early growing season demands for essential elements. This reliance upon stored reserves peaks during bud-break and diminishes as the new leaves mature. Consequently, trees begin to mine the soil for essential elements as the leaves are expanding. Regardless of the form of the fertilizer and the method used to deliver the fertilizer, the objective is to make the essential elements in the fertilizers become available during this time period.

Prescription Fertilization and Nutrient Management Plans

Tree fertilization is a management prescription that benefits trees in many ways. However, the misapplication of fertilizers can seriously affect the health and longevity of a tree and have tremendous adverse affects on the environment. As a result, arborists and landscape managers must develop nutrient management plans for the trees they are caring for. The nutrient management plan should address the trees' needs based on species, growth phase, and health, and the



BRYAN KOTWICA

From a biological perspective, trees will typically rely on stored reserves of the mobile macronutrients to meet the early growing season demands for essential elements.

soil's ability to meet the annual demand for essential elements. This plan should also identify potential limiting factors that may impede the ability of the soil to supply the essential elements, including landscape management practices that may negatively impact the trees' ability to acquire essential elements.

Les P. Werner is an associate professor of Urban Forestry with the College of Natural Resources, University of Wisconsin - Stevens Point (Stevens Point, WI).

CEU TEST QUESTIONS

Take your quiz online! Go to www.isa-arbor.com/certification/ceus.aspx and click on "Arborist News Quizzes Online." If you need a login and password, send an e-mail to cert@isa-arbor.com.

To receive continuing education unit (CEU) credit (1.0 CEU) for home study of this article, after you have read it, darken the appropriate circles on the answer form of the insert card in this issue of *Arborist News*. (A photocopy of the answer form is ***not*** acceptable.) A passing score for this test is 16 correct answers.

Next, complete the registration information, ***including your certification number***, on the answer form and send it to ISA, P.O. Box 3129, Champaign, IL 61826-3129. Answer forms for this test, **Tree Nutrition and Fertilization: Practical Considerations (Part II)**, may be sent for the next 12 months.

If you do not pass the quiz, ISA will send you a retake answer sheet. You may take the quiz as often as necessary to pass. If you pass, you will ***not*** be notified; rather, you will see the credit on your CEU report (available online). Processing CEUs takes 4 to 6 weeks.

CEUs for this article apply to Certified Arborist, Utility Specialist, Municipal Specialist, Tree/Worker Climber, and the BCMA practice category.

1. A complete fertilizer contains which of the following?
   a. nitrogen, phosphorous, calcium
   b. nitrogen, magnesium, sulfur
   c. potassium, iron, boron
   d. nitrogen, phosphorous, potassium
2. The composition and percentage of elements on a dry weight basis in a fertilizer is called the
   a. index
   b. analysis
   c. adjustment factor
   d. burn index
3. Which of the following management objectives replaces essential elements at a rate that is consistent with the amount of essential elements removed from the site through leaf and tree litter collection?
   a. growth promotion
   b. deficiency correction
   c. maintenance
   d. none of the above
4. What is the first step in correcting a nutrient deficiency?
   a. diagnose the underlying cause of the deficiency
   b. correct elemental deficiencies through fertilization
   c. eliminate competing vegetation
   d. double the rate of fertilization application until the deficiency has stabilized
5. According to the author, the growth-promoting rate of fertilization application is less than the maintenance rate of application.
   a. True
   b. False
6. Which type of application rate is best suited for newly established and senescing/very mature trees.
   a. growth promoting
   b. maintenance
   c. maximum allowable
   d. zero application
7. The nutrient management plan calls for 1.5 lbs of N per 1000 ft^2 of canopy coverage. The tree has a canopy spread of 2,500 ft^2. The fertilizer is 15-15-15. How much fertilizer must be applied to the tree?
   a. 15 lbs
   b. 25 lbs
   c. 30 lbs
   d. 45 lbs
8. Which type of essential elements are most appropriately applied using trunk injections?
   a. micronutrients
   b. macronutrients
   c. mobile elements
   d. immobile elements
9. Into which type of tissue are essential elements injected during the trunk injection method?
   a. vascular cambium
   b. phloem
   c. xylem
   d. heartwood
10. Which of the following application methods is most appropriate when nutrient management indicates a complete fertilizer is required for a tree growing in competition with a dense turfgrass?
    a. foliar
    b. sub-surface
    c. surface
    d. trunk injection
11. The greatest acquisition of essential elements derived from the soil generally occurs
    a. just prior to bud-break
    b. during dormancy
    c. shortly after bud-break
    d. during mid-summer
12. The baseline application rate for maintenance fertilization is
    a. 4 lbs of N per 1000 ft^2 of canopy coverage
    b. 3 lbs of N per 1000 ft^2 of canopy coverage
    c. 2 lbs of N per 1000 ft^2 of canopy coverage
    d. 1 lb of N per 1000 ft^2 of canopy coverage
13. The baseline application rate for growth promoting fertilization is
    a. 4 lbs of N per 1000 ft^2 of canopy coverage
    b. 3 lbs of N per 1000 ft^2 of canopy coverage
    c. 2 lbs of N per 1000 ft^2 of canopy coverage
    d. 1 lb of N per 1000 ft^2 of canopy coverage
14. What factors are taken into account when determining adjustments to the rate of application?
    a. tree, soil, landscape management factors
    b. tree, landscape management, time of year factors
    c. soil, landscape management, time of year factors
    d. soil, tree, time of year factors

15. Which of the following types of essential elements is most suitable for foliar applications?
    a. water insoluble
    b. water soluble
    c. complete
    d. incomplete
16. Essential elements required for early season growth come from
    a. atmospheric deposition
    b. soil derived
    c. stored reserves
    d. fertilization
17. Organic fertilizers containing carbon are derived from
    a. plant residues
    b. once-living organisms
    c. the atmosphere
    d. feldspars
18. Fertilizers are salts and can impair water uptake if they over-applied.
    a. True
    b. False
19. Mistimed or over-application of a fast-release fertilizer can result in
    a. volatilization
    b. evaporation
    c. leaching
    d. binding
20. Which of the following is not involved in regulating the breakdown and release of essential elements in slow release fertilizers?
    a. heat
    b. water
    c. soil microbes
    d. tree species