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Fertilizer Options in the Landscape

By Roger C. Funk

Why do urban trees need to be fertilized? Forest trees evolved without the apparent addition of fertilizer, which can give the erroneous impression that trees, in general, do not require fertilizer. In reality, forest trees are being fertilized through the natural process of recycling.

In addition, through the process of natural selection, trees have adapted over the millennia to the existing soil and environmental conditions. Conversely, shade and ornamental trees are often selected and planted for their aesthetic appeal without regard for their horticultural requirements in the urban environment. Thus, they are subjected to unfavorable soil and environmental conditions, which increases the need for nutrient management.

Forest soils are rich in humus, which is replenished by the decay of plant and animal residue. Leaves are relatively high in accumulated nutrients and their decomposition is an important source of returning nutrients to the soil. Forest research has demonstrated that trees obtain more than half of their annual requirements from these sources. Organic matter increases the retention and availability of most plant nutrients and improves the soil structure by "cementing" or aggregating soil particles. In contrast, domestic and street lawns are usually very low in humus and fertility. Leaves are removed, thus interrupting nature's recycling program for nutrients and preventing the accumulation of organic matter. The soil elements, which are absorbed and utilized in the formation of plant tissues, are not returned to the soil and should be replaced with supplemental fertilization.

How do woody plants use the nutrients from the soil?

Woody plants make their own sugar during photosynthesis by combining carbon dioxide from the air with water from the soil, a process driven by energy from the sun. Plants cannot live on sugar alone, however. They must have chlorophyll, proteins, defensive chemicals, and many other compounds and structures in order to maintain their metabolism and react to changes in their environment. Plant cells make these chemicals by combining the sugar provided by leaf tissue with nitrogen and the mineral elements absorbed from the soil. Slightly more than a dozen mineral elements are essential for plant growth and development, although only the ones that are utilized in large amounts are often deficient.

The most common deficiencies are of the three primary macronutrients: nitrogen, phosphorus and potassium. Some plants (called acid loving) require relatively large amounts of micronutrients and these may be deficient in alkaline soils, which "fix" or prevent their absorption by plants. The micronutrients are actually metals such as iron, manganese or zinc and may need to be supplemented when the so-called acid loving plants are growing in alkaline soils or in sandy soils that don't retain minerals.

What is the difference between organic and chemical fertilizers?

Actually, all fertilizers are chemical, including those that are organic. Fertilizers can be grouped into four broad categories, based on whether or not they contain carbon and whether or not they are synthetic.

<i>Organic</i>	<i>Inorganic</i>
Natural	Natural
Synthetic	Synthetic

"Organic" is the chemistry of carbon, not the chemistry of natural. All organic fertilizers have a carbon structure, which can be synthesized by an organism or in a laboratory using the same elements and the same chemical processes. Whether natural or synthetic, the nutrient ions are attached

<p>Natural Organic</p> $\begin{array}{c} \text{NH}_2 \\ \\ \text{C}=\text{O} \rightarrow \text{NH}_4^+ \rightarrow \text{NO}_3^- \\ \\ \text{NH}_2 \end{array}$ <p>Urea → Ammonium → Nitrate</p>	<p>Natural Inorganic</p> $\text{NaNO}_3 \rightarrow \text{Na}^+ + \text{NO}_3^-$ <p>Sodium Nitrate → Sodium + Nitrate</p>
<p>Synthetic Organic</p> $\begin{array}{c} \text{O} \\ \\ [\text{CH}_2\text{NHCNH}]_x \end{array} \rightarrow \text{NH}_4^+ \rightarrow \text{NO}_3^-$ <p>Methylene Urea Polymer → Ammonium → Nitrate</p>	<p>Synthetic Inorganic</p> $\text{NH}_4\text{NO}_3 \rightarrow \text{NH}_4^+ + \text{NO}_3^-$ <p>Ammonium Nitrate → Ammonium → Nitrate</p>



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to carbon and it is this structure that determines the characteristics of the organic chemical. Carbon forms covalent bonding that does not readily degrade; thus, the nutrient ions are released slowly. Although organic compounds are often thought of as energy sources for microorganisms (microbial breakdown), some are hydrolyzed by water.

Urea is a natural component of urine and bat guano, and is also commercially synthesized. Urea is an example of both a natural and synthetic organic fertilizer that is hydrolyzed. Two examples of fertilizer that require microbial breakdown are ureaform, a synthetic organic fertilizer, and alfalfa pellets, a natural organic fertilizer.

Organic fertilizers that require microbial decomposition also result in improved soil structure and other plant benefits. As these microorganisms decompose organic matter, they release nutrients and enzymes beneficial to living plants, and glue-like gums and waxes that form soil aggregates, which improve air and water movement in the soil.

Inorganic or mineral fertilizers do not have a carbon structure and can occur naturally or be synthesized with simple ionic bonding. These bonds form nutrient salts that dissociate readily in water, releasing the nutrient ions. Potassium nitrate is an example of an inorganic fertilizer that occurs naturally and is also synthesized. Since they do not contain carbon, inorganic or mineral fertilizers are not used as an energy source by microorganisms and have no beneficial effect on the soil. They are said to "feed the plant, but not the soil". The nutrients are typically more highly concentrated than in an organic fertilizer and are more readily available for plant absorption.

Inorganic or soluble organic fertilizers such as urea can be coated with a plastic or wax resin to slow the nutrient release rate. Although considered a slow release form of nutrients, these fertilizers are hydrolyzed and do not result in soil improvement.

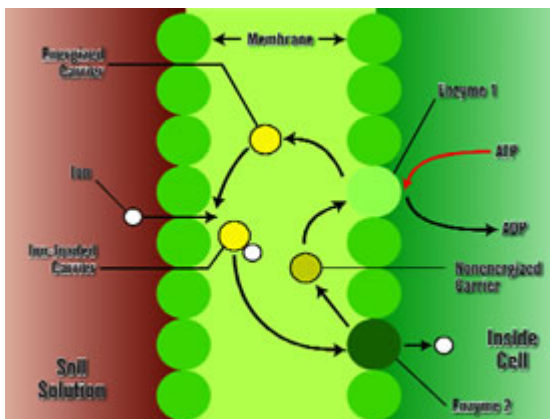
How is fertilizer absorbed?

All fertilizer nutrients, regardless of the source, are absorbed by plant roots as charged atoms or groups of atoms called ions - the nutrient salts. These ions exhibit either a positive or a negative charge, which is essential for root absorption. Fertilizer salts or ions are absorbed through the root membrane by electrical attraction to a carrier. The process primarily responsible for nutrient absorption is called ion exchange.

Inorganic fertilizers form ions readily when dissolved in water and, therefore, are quickly available for root absorption. Organic fertilizers - both natural and synthetic - must be decomposed by soil microorganisms from complex compounds to the same nutrient salts provided by inorganic fertilizers. The rate of decomposition is dependent upon many soil factors such as temperature, moisture and pH.

Absorption is one of the main functions of roots. Without their constant supply of water and nutrients, a tree could not survive. However, absorption is the part of the process that we don't entirely understand.

Until minerals cross a cell membrane, absorption is passive and often on a diffusion gradient (from high nutrient concentrations to lower concentrations). However, the only way for minerals to get past a barrier in the root called the endodermis and into the xylem is through a cell membrane.



One of the jobs of cell membranes is to regulate what goes in and out of a cell. If the membrane was full of holes, the cell would die because its contents would leak out. Yet, there must be some way for materials to get through the cell to give it the ions it needs. Scientists believe there are several mechanisms for minerals to get across the membrane. One is a carrier that transports ions.

The carrier system can be an essentially passive process. Because the cell is constantly using the ions, nutrient concentrations can be higher on the outside than on the inside of the cell. The carrier system then facilitates and speeds uptake. However, when concentrations inside the cell are



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greater than those outside it, passive uptake is impossible. In some instances, ion concentrations may be 1,000 times greater within the cell. Then, the cell must expend energy to take up the ion. Working with carriers, a substance called ATP undergoes a chemical reaction within the cell to provide that energy.

It is important to understand that the plant expends energy to absorb nutrients. When a plant is in a weakened state, such as from drought, low temperatures or lack of oxygen, it does not accumulate nutrients because energy is not available to take them up.

It is not yet clear whether each specific ion has its own carrier, but it seems that this is likely - at least for nutrients absorbed in large amounts, like nitrate, phosphate and potassium. It is possible that there are dual absorption systems for many ions and that ions with similar properties must compete for the same absorption sites. If a soil is high in clay or organic matter, it can retain these ions rather than lose them from leaching. The structure of clay and organic matter creates charged sites that hold the ions on their surface. Both have negatively charged sites that attract positively charged ions (cations). These charged sites relate to a soil's cation exchange capacity (CEC), a measure of the soil's ability to hold cations. If a soil has a high CEC, it has the ability to hold large amounts of cations. Organic matter also has positively charged sites that hold negatively charged ions (anions).

When soil is moist, an active equilibrium develops in the soil solution so that its composition is constantly changing. Cations in the soil solution exchange places with cations at the charged sites. Plants absorb cations and anions from the soil solution. Some anions and cations leach away. Decomposition releases new ions to replace them.

Can fertilizer "burn" plants?

Yes, if there is an excess of soluble or quick-release fertilizer salts in the root zone.

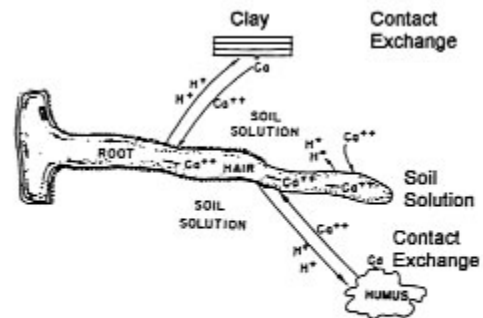
Leaf "burn" is a visible symptom of insufficient water in a plant. Water moves through the root tissues in response to a concentration gradient on the outside of the root and from inside the root tissue. Water moves from a region of low salt concentration to a region of high salt concentration until the concentration on both sides of the root is equal. As water within a plant system is transpired, a higher salt concentration occurs within the root tissue than in the surrounding soil solution. However, if excessive fertilizer salts are in the root zone, water movement into root cells is suppressed. Under extreme conditions, water actually moves from the root tissue into the surrounding soil solution. The movement of water through root tissue is called osmosis.

The tendency for a fertilizer to dissolve and release salts when in contact with water is known as the SALT INDEX. The amount of salt released by sodium nitrate is given the arbitrary salt index of 100, and all other fertilizer salt indices are relative to sodium nitrate. The greater the amount of salts released, the greater the salt index and the higher the burn potential. In general, inorganic fertilizers have higher salt indices than organic fertilizers.

How does soil pH affect nutrient absorption?

The term pH expresses the relative concentration of hydrogen (H^+) and hydroxyl ions (OH^-) in solution. A pH of 7 means the hydrogen and hydroxyl ions are equal and the solution is said to be neutral. A pH below 7 means the solution contains more hydrogen ions than hydroxyl ions and is said to be acid. Similarly, a pH above 7 means the solution contains more hydroxyl ions and is alkaline.

The soil pH may influence nutrient absorption and plant growth through the effect of the hydrogen ion and through the indirect influence on nutrient availability. In most soils, the latter effect is the most significant.



Diagrammatic scheme showing how root hair takes in nutrients from exchangeable ions on a clay crystal and on humus, and from soil.



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The presence of an element in the soil is no guarantee that it is in a soluble form available for absorption. The concentration of hydrogen and associated ions affects soil reaction and the formation of soluble and insoluble compounds. All nutrients must be soluble to be available for root absorption. Each nutrient has a pH range of maximum availability simply because within this range it forms a large proportion of soluble compounds.

Plant species differ in their response to the soil acidity because differences in nutrient requirements. For most plants, the conditions of nutrient availability, without toxic amounts are best near pH 6.5. But certain plants - such as rhododendrons, azaleas, pines and camellias - require comparatively large amounts of nutrients that are soluble in acid solution. They are called "acid loving" plants and grow best in soils of about pH 5.5.

Soil acidity, as such, is seldom toxic to plants. But, in soils with pH values below 5.5, certain elements, such as aluminum or manganese, often become soluble to levels toxic to plant growth.

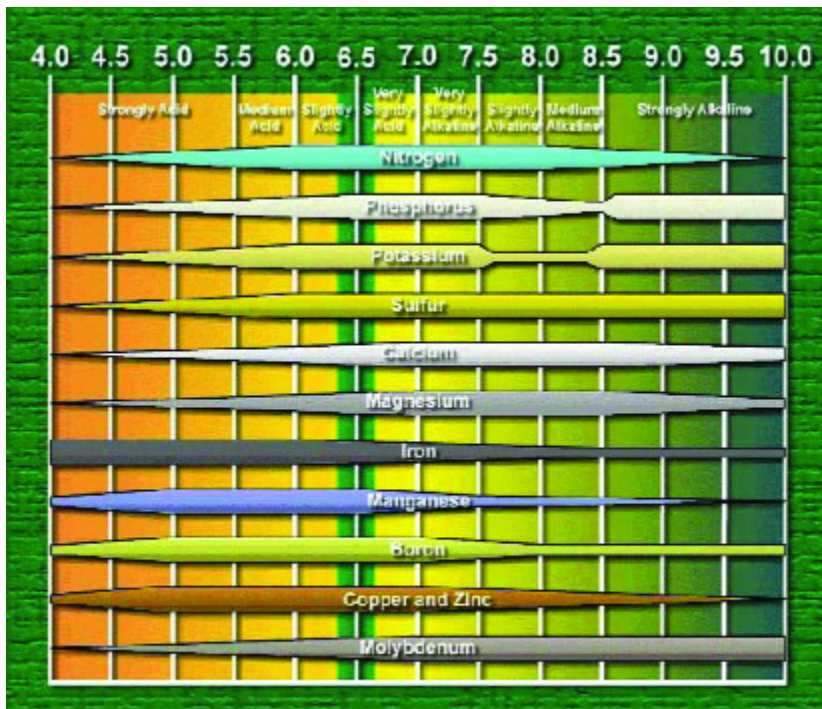
Sulfur and agricultural lime are the materials used most frequently to alter the soil reaction or pH. Lime increases the pH (decreases acidity); sulfur lowers the pH (increases acidity).

Ideally, the pH of soil within the root zone of a plant should be measured every three to five years and, if necessary, adjusted to the most favorable range for that particular species.

What is leaching?

Leaching, primarily, is the removal of materials in solution from the soil. Leaching is caused by percolation or the lateral and downward movement of water through soil. Loss of nutrients due to leaching is proportional to the amounts of water percolated through the soil. Water dissolves minute quantities of minerals and organic materials just as sugar dissolves in coffee. Dissolved substances commonly move with the water.

Since soil and weather conditions vary throughout the United States, leaching affects soils of humid regions more, on the whole, than it does those of dry regions.



Bar width indicates the relative availability of each element with a change in soil reaction. The pH for greatest availability for almost all nutrients is about 6.5.

All nutrients are subject to leaching, although not to the same degree. Calcium losses are the greatest of any nutrient known. Nitrate salts - the form of nitrogen primarily absorbed by plant roots - moves with ground water and rapidly leaches from the root zone. Magnesium, sulfur and potassium are moderately leached, whereas only a trace of phosphorus is lost.

Nitrate leaching is becoming a major concern, particularly as it relates to point source pollution. Several research studies with turfgrass have demonstrated minimal leaching risk from surface-applied nitrogen fertilizers. However, with urban tree fertilization, nitrogen injected below the soil surface would not be "trapped" by the turf. Davey researchers completed a two year study in 2003 to compare leaching of urea, ammonium, and nitrate from soluble and insoluble sources injected into the soil.



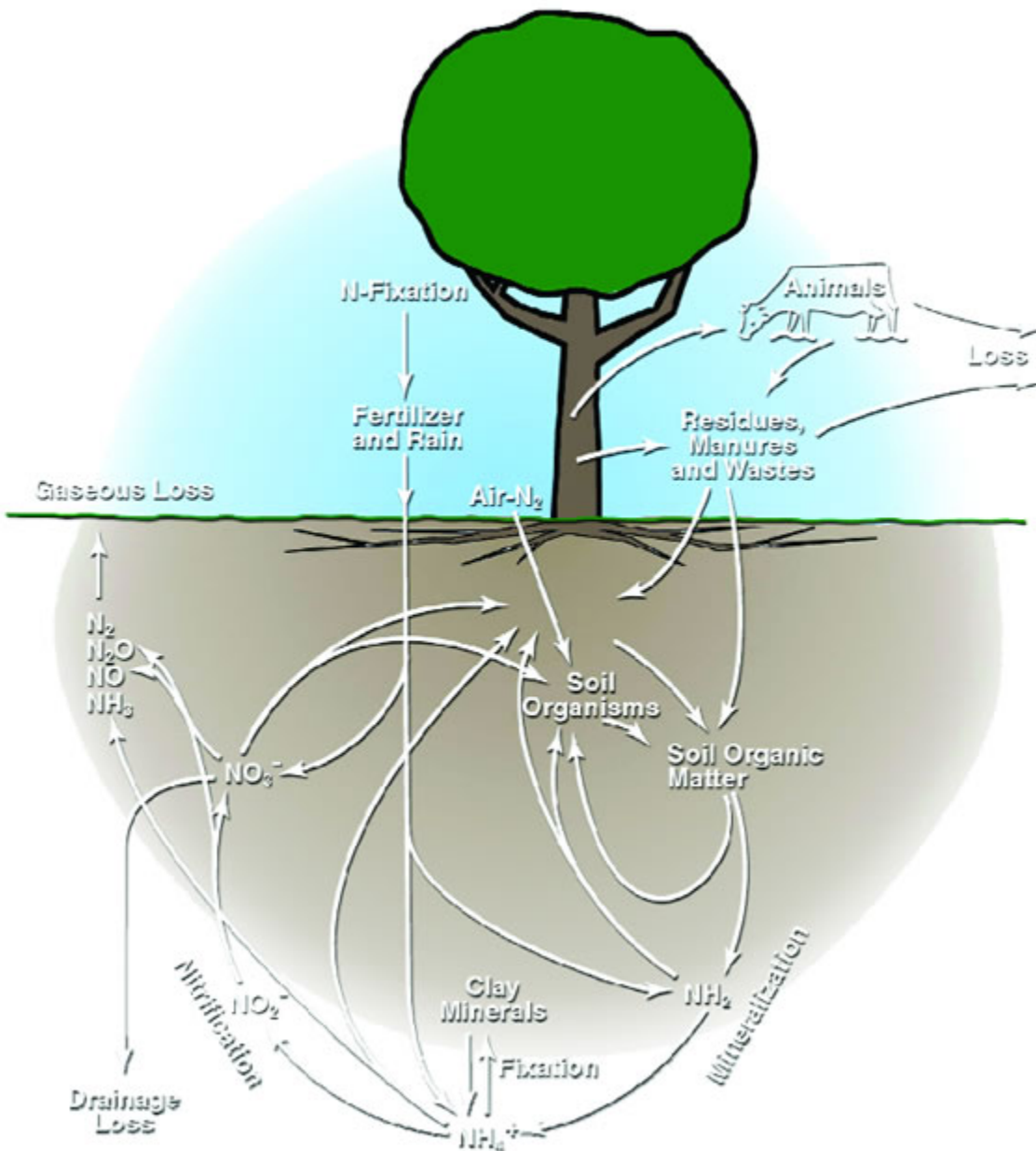
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In this subsurface fertilization study in which slow release and soluble fertilizer were applied at 3# N (3 pounds of nitrogen) per 1,000 square feet, there was no evidence of any inherent risk to ground water quality due to nitrate, ammonium or urea leaching from either fertilizer applied within the drip-line of sugar maple trees. However, both nitrate and ammonium were detected at the 27-inch depth from soluble nitrogen applied to the field area.

Nitrate levels in samples collected 27 inches below the fertilizer applications beneath the canopy of trees were not significantly different from nitrate levels found in unfertilized control plots. The nitrate readings ranged from 0.10ppm to 1.34ppm from slow release fertilizer and 0.067ppm to 13.1ppm from soluble fertilizer. Nitrate levels in samples collected 27 inches below the soluble fertilizer applications in the field area steadily increased throughout the collection period and were significantly higher at 52 DAT (days after treatment) when compared to the slow release and unfertilized treatments.

Both ammonium and urea levels measured in samples collected 27 inches below slow release and soluble applications in the tree area were not significantly different from the untreated control at either 3 or 7 DAT. However at 3 DAT in the field area, ammonium was significantly higher and remained higher at 7 DAT, although not significant.



Although neither slow-release nor soluble nitrogen fertilizer applications resulted in leaching at the 27-inch depth when applied within the root zone of sugar maple trees, soluble fertilizer applied in the field area where no tree roots existed did result in leaching of nitrate and ammonium. Slow release nitrogen provided added assurance that fertilizer injected at a depth of 4 to 12 inches in the soil will not leach, particularly if it is not utilized efficiently.

Further research is planned comparing slow release and soluble fertilizer applied in sandy soils, which have a greater potential for nitrogen leaching than typical landscape soils containing clay.



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How can a root/shoot imbalance occur?

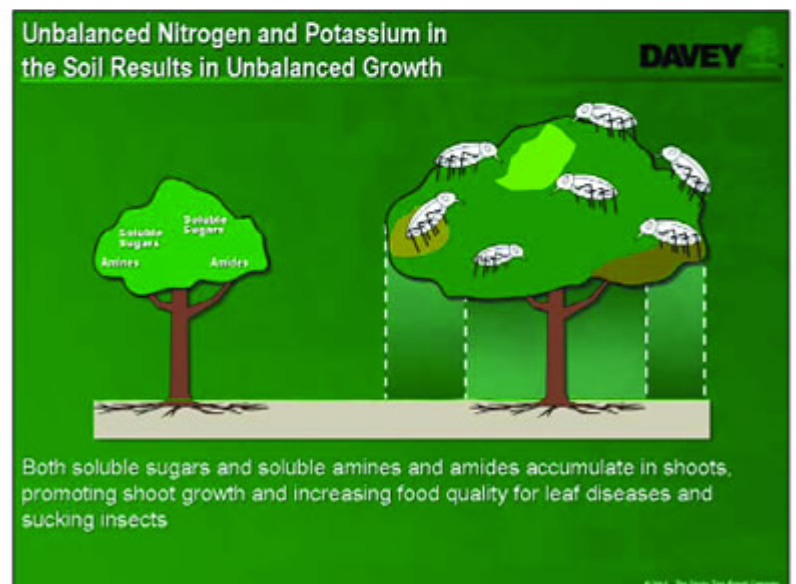
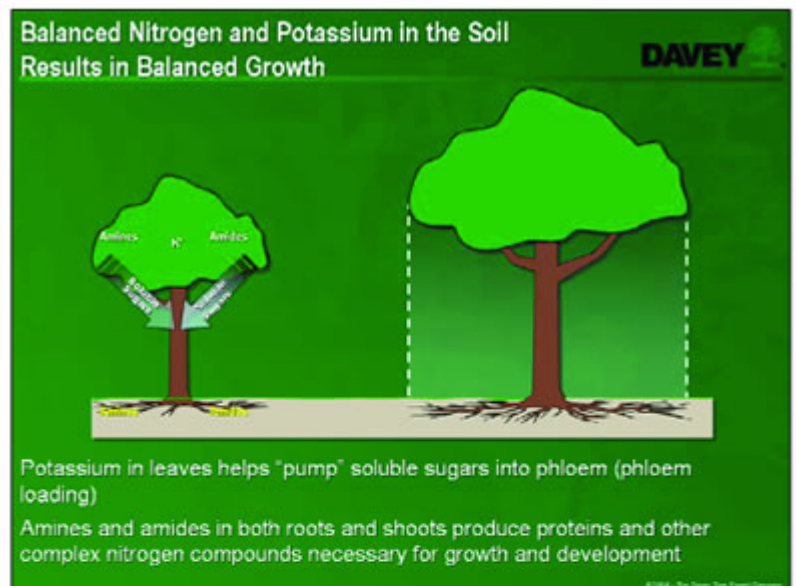
Unfortunately, specific research with applications of soluble nitrogen alone has mistakenly given the impression that fertilizers, in general, promote shoot growth at the expense of root growth. In fact, proper fertilization is essential to the balanced growth of woody plants in the landscape and is particularly important when trees are under stress or injured.

Nitrogen and the essential mineral elements are extracted from the soil by the root system and combined with sugar from the leaves to make complex chemicals in the growth and development of woody plants. New cells, including those initiated when the root system is injured, or defense chemicals produced in response to stress, cannot form without these elements. Under natural conditions, the nutrients are recycled during the decay of leaf litter. The decay process, which releases soluble nitrogen slowly, is essential to the proper growth of plants and a key to the proper fertilization of woody plants.

Woody plants have evolved with a continuous, low-level supply of nitrogen throughout the growing season, particularly in relation to available potassium. When grown in the landscape, woody plants are often deficient in nitrogen because the leaf litter is removed and turfgrass, which is more competitive for the same nutrient elements from the soil, planted in its place. Leaf litter is not only a natural source of nitrogen in the soil but also the primary storehouse for nitrogen. Mineral matter - sand, silt and clay - does not retain nitrogen, which can readily leach without the proper amount of organic matter. Unlike forest soils, landscape soils typically have less than 1 percent organic matter. Next to water, nitrogen deficiency is thought to be the most limiting factor in the growth and development of landscape plants, and supplemental nitrogen is the most common form of fertilization.

Although nitrogen applications are often necessary, if done improperly, excess soluble nitrogen in relation to available potassium can upset the physiology of the plant, resulting in additional stress. Nitrogen is always absorbed by root cells in the charged or ionic state, usually as Nitrate (NO_3^-) or Ammonium (NH_4^+). However, nitrogen normally does not translocate in the vascular system to other parts of the plant in these forms. Rather, an enzyme in the root cells converts nitrate or ammonium to amines or amides, low-molecular weight organic compounds that are precursors to proteins and other complex organic compounds. Some of the amines or amides remain in the root system and some translocate to the shoot system. Thus, all parts of the plants have the base materials to build proteins and other complex chemicals that contain nitrogen. Potassium is essential in the production and activation of this enzyme.

However, when excess nitrate and ammonium are in the root area, as could occur when soluble nitrogen is over-applied in relation to available potassium, the enzyme system in the roots is overwhelmed and nitrogen translocates as nitrate. This initiates a series of physiological changes in the plant that can lead to a root/shoot imbalance and an increase in sucking insects and certain leaf diseases.





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When nitrate translocates to the shoot system in the xylem, nitrate reductase enzyme (a large and complex enzyme) forms in the leaf cells, resulting in the conversion to amines and amides in the leaves. Potassium in the leaf cells that is used in conjunction with the enzyme is not available for "phloem loading," a process that moves sugar into the phloem against a concentration gradient. Thus, the first step in the translocation of sugar to other parts of the plant is affected and sugar accumulates in the leaf cells. Also, there is no evidence that the amines or amides formed in the leaf translocate downward in the phloem to the root system to serve as building blocks for cellular growth and activity in root tissue. The accumulation of soluble sugar and organic nitrogen compounds in the leaf cells results in succulent tissue and more favorable food quality for sucking insects and leaf diseases. In addition, the resulting sugar and organic nitrogen deficiency in root cells suppresses the growth and development of the root system.

In summary, woody plants evolved a mechanism to absorb, translocate and utilize soil nitrogen and the mineral elements based on conditions found in a forest. Landscape soils are often devoid of organic matter and attempts to replace the nitrogen lost through plant absorption and leaching should mimic the natural, slow release of organic matter in order to maintain the proper plant physiology. Research and experience demonstrating root/shoot imbalance or pest problems of woody plants following fertilization can be attributed to excess soluble nitrogen, particularly in relation to the available potassium.

What is the best method to fertilize woody plants?

The roots of woody plants do not go dormant and do not harden-off more than a few degrees to adverse temperatures as does the shoot system. In general, non-woody roots of trees in the temperate zone will withstand temperatures as low as about 28 degrees F and as high as 94 degrees F. For trees growing in the forest, the roots are protected from excessive fluctuations in temperature and moisture by leaf litter and other debris that accumulates on the soil surface.

In the urban environment, however, leaves are typically removed and replaced with turfgrass, which does not buffer adverse environmental conditions and actually competes with trees for the growth factors in the soil. In addition, heavy clay or compacted soil impedes oxygen and water penetration and movement, resulting in surface rooting. The surface of the soil becomes the hottest, coldest and driest during temperature and moisture extremes. Trees growing under these conditions benefit from subsurface applications of nutrients that encourage deeper rooting to avoid competition and injury. Suspending fertilizer in a water carrier, which is injected under pressure at a depth of 4 to 12 inches, creates capillaries that enhance air and water movement while distributing nutrients throughout the desirable root zone.

Roger C. Funk, Ph.D., is vice president and chief technical officer of The Davey Institute at The Davey Tree Expert Company. This article was excerpted from his presentation on the subject at TCI EXPO 2007 in Hartford.